Telecommunications Transmission Engineering

Volume 1
Principles

AT&T

Telecommunications Transmission Engineering

Volume 1 — Principles

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Introduction

Communication Engineering is concerned with the planning, design, implementation, and operation of the network of channels, switching machines, and user terminals required to provide communication between distant points. Transmission Engineering is the part of Communication Engineering which deals with the channels, the transmission systems which carry the channels, and the combinations of the many types of channels and systems which form the network of facilities. It is a discipline which combines many skills from science and technology with an understanding of economics, human factors, and system operations.

This three-volume book is written for the practicing Transmission Engineer and for the student of transmission engineering in an undergraduate curriculum. The material was planned and organized to make it useful to anyone concerned with the many facets of Communication Engineering. Of necessity, it represents a view of the status of communications technology at a specific time. The reader should be constantly aware of the dynamic nature of the subject.

Volume 1, *Principles*, covers the transmission engineering principles that apply to communication systems. It defines the characteristics of various types of signals, describes signal impairments arising in practical channels, provides the basis for understanding the relationships between a communication network and its components, and provides an appreciation of how transmission objectives and achievable performance are interrelated.

Volume 2, *Facilities*, emphasizes the application of the principles of Volume 1 to the design, implementation, and operation of transmission systems and facilities which form the telecommunications

network. The descriptions are illustrated by examples taken from modern types of facilities most of which represent equipment of Bell Laboratories design and Western Electric manufacture; these examples are used because they are familiar to the authors.

Volume 3, *Networks and Services,* shows how the principles of Volume 1 are applied to the facilities described in Volume 2 to provide a variety of public and private telecommunication services. This volume reflects a strong Bell System operations viewpoint in its consideration of the problems of providing suitable facilities to meet customer needs and expectations at reasonable cost.

The material has been prepared and reviewed by a large number of technical personnel of the American Telephone and Telegraph Company, Bell Telephone Companies, and Bell Telephone Laboratories. Editorial support has been provided by the Technical Publications Organization of the Western Electric Company. Thus, the book represents the cooperative efforts of many people in every major organization of the Bell System and it is difficult to recognize individual contributions. One exception must be made, however. The material in Volume 1 and most of Volume 2 has been prepared by Mr. Robert H. Klie of the Bell Telephone Laboratories, who was associated in this endeavor with the Bell System Center for Technical Education. Mr. Klie also coordinated the preparation of Volume 3.

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Volume 1 — Principles

Preface

This volume, comprised of five sections, covers the basic principles involved in transmitting communication signals over Bell System facilities. Section 1 provides a broad description of the transmission environment and an overview of how transmission parameters affect the performance of the network. The second section consists of a review of most of the mathematical relationships involved in transmission engineering. A wide range of subjects is discussed, from an explanation of and justification for the use of logarithmic units (decibels) to a summary of information theory concepts.

The third section is devoted to the characterization of the principal types of signals transmitted over Bell System facilities. Speech, television, PICTUREPHONE®, digital and analog data, address, and supervisory signals are described. Multiplexed combinations of signal types are also characterized. The fourth section describes a variety of impairments suffered by signals transmitted over practical channels, which have imperfections and distortions. Also discussed are the units in which impairments are expressed and the methods by which they are measured. The fifth section discusses the derivation of transmission objectives, gives many established values of these objectives, and relates them to requirements applied to system design and operation. The section concludes with a chapter on international communications and internationally applied transmission objectives.

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Section 1

Background

The Bell System should be regarded as a single, huge, and far-flung telecommunications system made up of station sets, cables, switching systems, transmission systems, wires, and a conglomeration of other hardware of all sorts and sizes. This telecommunications system has grown rapidly and is still growing at a rapid rate. It has within it a large number of interconnected and interrelated systems and subsystems, each of which was designed with an approach that provided for successful development and overall Bell System evolution. This relationship between the parts and the total has permitted the orderly growth of a giant and the rendering of telecommunications services throughout the United States, Canada, and indeed the world.

Historically, the first telephone systems consisted of two remote station sets interconnected by wires normally used for telegraph communications. As interest in telephone communication built up, the transmission capabilities of the station sets and the interconnecting wires were gradually improved. Soon, manually operated switching systems were introduced in local communities to provide flexible interconnections among people living close together and sharing a high community of interest. These switching systems and the surrounding station sets and interconnecting wires have become known as the *local plant.*

The expanding local areas, the increasing demands for a wider range of services, and improvements in technology soon permitted the interconnection of one central office with another. As these interconnections increased in numbers and distances over which service had to be provided grew larger, the evolving long distance network became a separate entity known as the *toll plant.* Larger and more complex switching and transmission systems were designed to meet the unique needs of this part of the overall system.

Chapter 1 provides an overview of the operating Bell System plant with emphasis on the transmission and switching facilities that provide nationwide telephone service. Equipment used for other services that share the message network facilities is also briefly discussed.

An introduction to transmission concepts is given in Chapter 2. Brief descriptions of telephone, program, television, and data signals are presented, transmission terminology is defined, and basic techniques and modes of transmission are explained. Some specialized equipment, used to improve plant performance, is described to illustrate the interactions of various parts of the network.

Chapter 1

The Transmission Environment

The Bell System provides a variety of communications services to large numbers of people over a very wide geographical area. To accomplish this task, a vast and complex physical plant has evolved. This plant is by no means static; it is highly dynamic in terms of growth, change, and the manner in which it is used for providing customer services.

The services provided by the Bell System are not readily categorized. The basic service of voice communications is handled by what is known as the switched message network; however, some services such as telegraph, facsimile, and voiceband data also utilize this network. In addition, a growing list of other services (e.g., point-to-point private line, television network service, wideband data, etc.) are provided, some of which require special switching arrangements and some of which require no switching at all.

The provision of transmission paths, or channels, and the flexible interconnection of these paths by switching are the two principal functions performed by the switched message network, the largest of the service categories that use the plant. The facilities involved are shared by many other services provided by the Bell System. The network transmission paths, highly variable in length, are of two major types, customer loops and interoffice trunks. The switching arrangements are also of two major types, local and toll. The design, operation, and maintenance of this huge network is further complicated by the multiplicity of its parts.

1-1 TRANSMISSION PATHS

Transmission paths are designed to provide economic and reliable transmission of signals between terminals. The designs must accom-

modate a wide range of applied signal amplitudes and must guarantee that impairments are held to acceptably low values so that received signals can be recovered to satisfy the needs of the recipient, whether a person or a machine.

Many transmission paths are designed as two-wire circuits; that is, transmission may occur simultaneously in both directions over a single pair of wires. Other paths, voice-frequency or carrier, are designed as four-wire; each of the two directions of transmission is carried on a separate wire pair.

The four major elements in transmission paths are station equipment (telephones, data sets, etc.), customer loops (cables and wires that connect station equipment to central offices), local and toll trunks (interconnections between central offices, consisting of cables or transmission systems and the transmission media they use), and the switching equipment (found primarily in the central offices). In its simplest form, a transmission path might consist of two station sets interconnected by a pair of wires.

The Station Set

The station set accepts a signal from a source and converts it to an electrical form suitable for transmission to a receiver which reverses the process at a distant point. In most cases the station set is a telephone; however, many other types of station sets are used. Examples include facsimile sets, which operate to convert modulated light beams to modulated electrical analog signals and back to light at the receiving station, and voiceband data sets, which translate the signal format used by a computer to an electrical representation suitable for transmission over the telephone network and then back to the appropriate computer signal format. Many of these types of sets must meet transmission requirements for voice communications.

Customer Loops

The station set is connected to the central office by the customer loop. This connection is most commonly made through a pair of insulated wires bundled together with many other wire pairs into

a cable which may be carried overhead on poles, underground in ducts, or buried directly in the ground. For urban mobile service, however, the loop consists of a radio connection between the station set and the central office. The design of the customer loop must satisfy transmission requirements for all types of signals to be carried, e.g., speech, data, dial pulsing, TOUCH-TONE®, ringing, or supervision.

Loops are busy (i.e., connected to trunks or other loops) only a small percentage of the time — in some cases, less than 1 percent of the time. Where suitable calling patterns exist, this has led to the consideration of line concentrators for introduction between the station sets and the central office. A concentrator is a small switching machine which allows a number of loops to be connected to the central office over a smaller number of shared lines which are, in effect, trunks.

For some services, the loop plant is frequently reconfigured. In providing private branch exchange (PBX) services, for example, the loop plant provides PBX trunks connecting the customer's switching arrangement to the local or serving central office. In other services, loop plant may be used to form a part of a loop to be intermixed with trunks to provide an extended loop, or it may be used as a part of a channel between various customer locations for the transmission of wideband signals.

Switching Machines

For switched message telephone service, the loop connects the station set to a switching machine in the local central office, which enables connections to be established directly to other local station sets or, through trunks and other switching offices, to any other station set on the switched network. The various types of switching offices which house this equipment are illustrated in Figure 1-1.

The principal switching machines in use today are electromechanical, e.g., the step-by-step and the crossbar types. Coming into increasing use, however, are electronic switching systems, which provide improvements in flexibility, versatility, and ease of maintenance, along with a considerable reduction of space requirements.

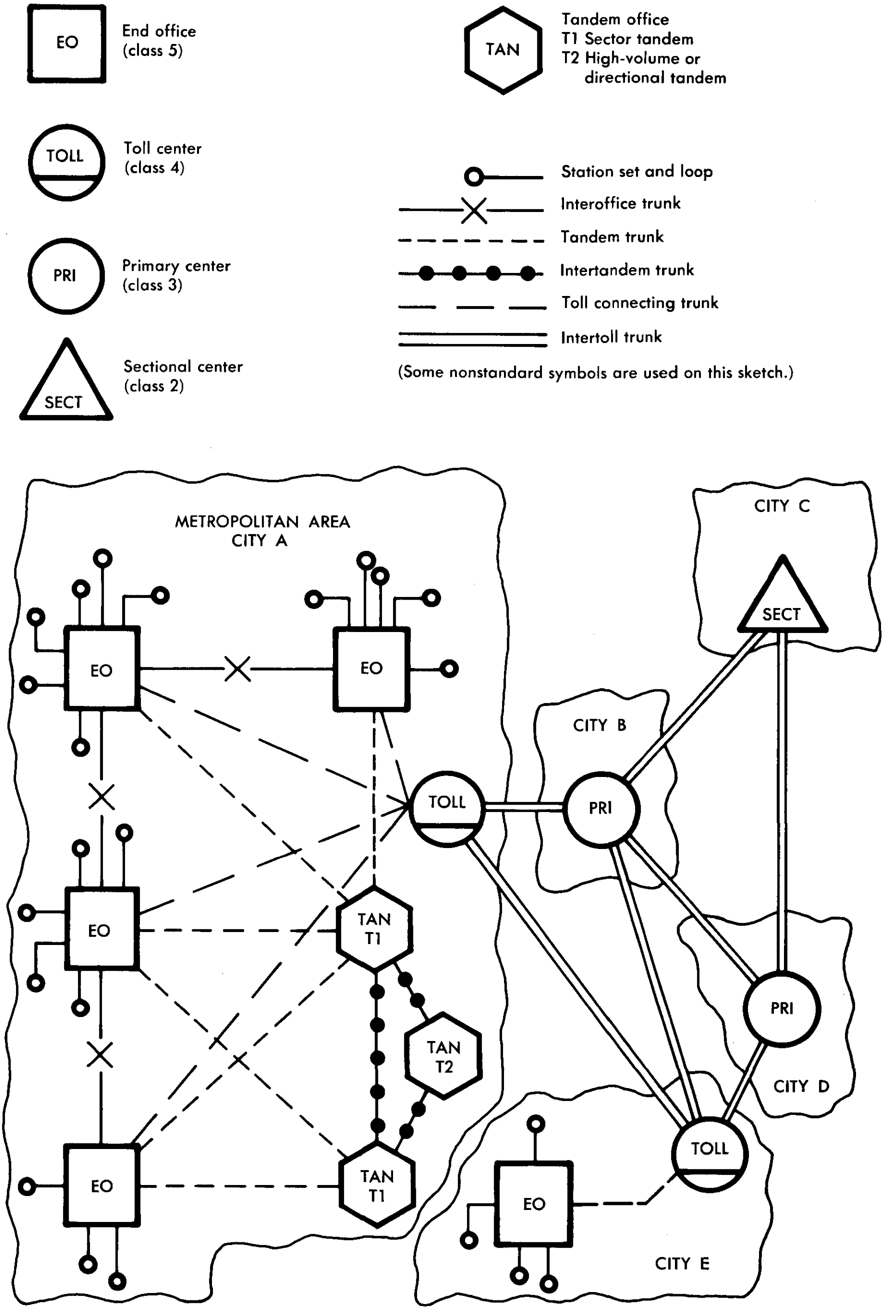


Figure 1-1. A simplified telephone system.

Transmission paths are provided through switching machines in a variety of ways and by a number of different mechanisms, including step-by-step switches, crossbar switches, and ferreed switching networks. These all have one thing in common, the ability to connect any one of a set of several thousand terminals to any other in the set. By design, this is accomplished with only a minimum of blocking during the busiest hour; i.e., only a very small percentage of calls is not completed as a result of all paths being busy. Each of the many paths is designed to provide satisfactory transmission quality through the central office.

As mentioned earlier, many transmission circuits are operated on a two-wire basis and, as a result, are also switched on a two-wire basis. Thus, especially in the local area, most switching machines provide two-wire paths. In the toll network, most of the transmission paths are four-wire; as a result, many toll switching machines must provide four-wire switching and transmission paths.

Trunks

The transmission paths which interconnect switching machines are called trunks. One essential difference between a loop and a trunk is that a loop is permanently associated with a station set, whereas a trunk is a common connection shared by many users. There are several classes and types of trunks depending on signalling features, operating functions, classes of switching offices interconnected, transmission bandwidth, etc.

There are three principal types of interoffice trunks: local (interoffice, tandem, and intertandem), toll connecting, and intertoll. These trunk types and the switching offices that they interconnect are illustrated in Figure 1-1 which shows a representative metropolitan area and typical connections to the toll portion of the network.

All trunks must provide transmission and supervision in both directions simultaneously. However, trunks are designated *one-way* or *two-way* according to whether signalling is provided in both directions or only one. Two-way signalling is usually provided on intertoll trunks; calls can be originated on the trunk from the switching machine at either end. One-way signalling is the usual method of

operating local and toll connecting trunks; therefore, separate trunk groups are provided for the two directions of originating traffic between the two offices involved.

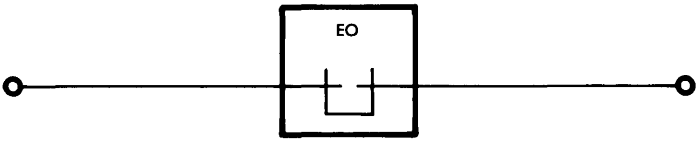
Any trunk may use carrier transmission systems. However, local and toll connecting trunks rely heavily on voice-frequency cable media, although short-haul analog and digital carrier systems are becoming more widely used, especially in large metropolitan areas. The intertoll trunks, for the most part, utilize long-haul analog carrier systems and microwave radio relay systems.

1-2 SWITCHING ARRANGEMENTS

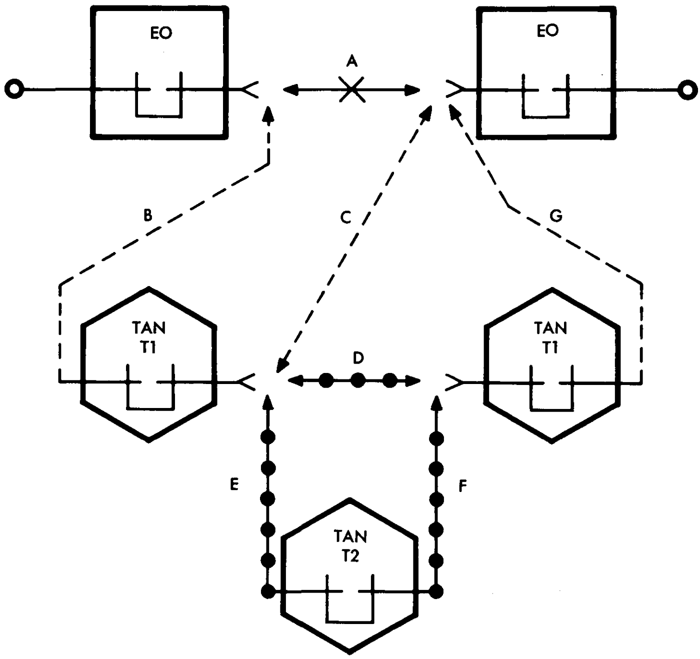
The service offered by the Bell System consists fundamentally of providing transmission capability upon demand between two or more points. Implied by "upon demand" is a switching arrangement capable of finding the distant end or ends of a desired connection and completing the connection between the originating and distant ends promptly and accurately. This is accomplished by a large number of switching machines connected together and organized around considerations of geography, concentrations of population, communities of interest, and diversity of facilities. These switching arrangements are illustrated in Figure 1-1 and may be broadly classified as either the local switching hierarchy (utilized for local transmission) or the toll switching hierarchy (utilized for transmission outside the local area). The switching equipment of either arrangement, however, is not totally divorced from that of the other. For example, tandem offices, operated by an associated company, are frequently used to switch toll traffic. Two methods are used. One is to segregate trunks between interlocal and toll use by maintaining separate groups. The second is to use a common tandem trunk group for both toll and interlocal. When trunks are so shared, the more severe transmission requirements for either use must be applied to the common group.

The Local Switching Hierarchy

Figure 1-2 illustrates the various degrees of complexity that may be involved in switching within a local area. The simplest connection



(a) Station-to-station connection; same end office



(b) Station-to-station connections using local trunks

Note:
Symbols are same as in Figure 1-1.

Figure 1-2. Illustrative telephone connections.

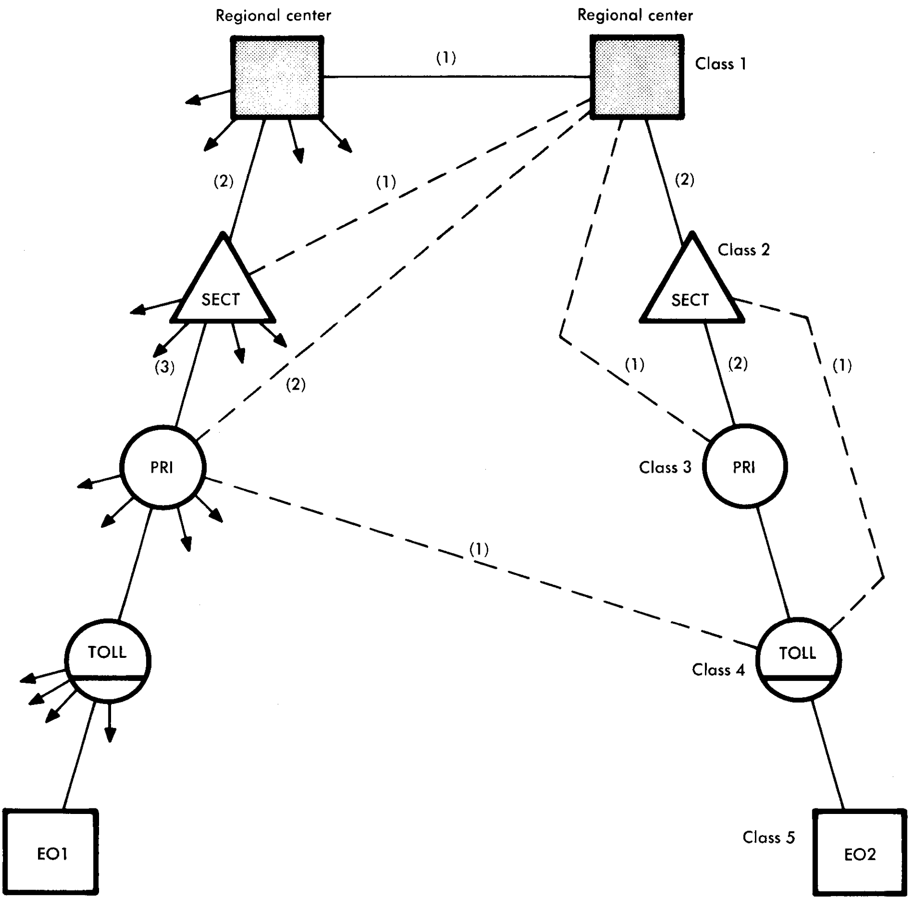
in the switched network is from one station set to another through a single local central office. Transmission over such a connection involves only the two station sets, their loops, and the transmission path through the switching machine as shown in Figure 1-2(a).

A connection in a multioffice area might be set up between two local, or class 5, offices in a number of ways as shown in Figure 1-2(b). Within the metropolitan area, it can be seen that trunks might interconnect two offices directly, using trunk A. Alternately, one, two, or three tandem switching machines might be used; with one machine, trunks B and C are used; with two machines, trunks B, D, and G are used. Finally, if three machines are involved, trunks B, E, F, and G are all used. These tandem machines, used in large metropolitan areas, provide economies through switching versus trunk facility costs and also provide alternate routing of traffic.

The complexity of the transmission network is obviously increased by this multitrunk local area switching arrangement, which is quite separate from the toll switching hierarchy discussed below. Since a connection might use just one interoffice trunk between the two end offices or as many as four tandem and intertandem trunks interconnecting the end offices and the tandem offices, the network arrangement must be designed and built according to objectives that take into account the number of trunks that might be connected together in tandem to complete a connection from one station to another. While local trunks are usually short, their numbers comprise the largest segment of trunks in the Bell System.

The Toll Switching Hierarchy

The hierarchy of toll switching offices, developed to facilitate the transmission of signals beyond a local area, is illustrated in Figure 1-3. Working from the top down, it can be seen that the hierarchy consists of regional centers, sectional centers, primary centers, toll centers, and end offices. These centers and offices are also classified by a numbering system as shown in Figure 1-4. The figure also shows the quantity of each type of office operating in the Bell System in early 1970.



Notes:

1. Numbers in ( ) indicate order of choice of route at each center for calls originating at EO1.

2. Arrows from a center indicate trunk groups to other lower rank centers that home on it. (Omitted in right chain.)

3. Dashed lines indicate high-usage groups.

Figure 1-3. Choice of routes on assumed call.

CLASS	DESIGNATION	APPROXIMATE NO. IN SERVICE, 1970
1	Regional center	10*
2	Sectional center	50
3	Primary center	200
4	Toll center	1000
5	End office	10,000-15,000

*In addition to the ten regional centers in the U.S.A., there are two in Canada.

Figure 1-4. The toll switching hierarchy (Bell System only).

Access to the toll network is made through toll connecting trunks. In general, they are classified with local trunks since they are relatively short and intermixed on facilities with interoffice, tandem, and intertandem trunks. Generally, toll connecting trunks provide connections between class 5 and class 4 offices (end offices and toll centers). However, since class 5 offices may connect into the toll network at any level of the hierarchy, toll connecting trunks may also connect to class 3, class 2, or class 1 offices as well as to class 4 offices. In these cases, the higher offices also perform the functions of class 4 offices. The facilities used by toll connecting trunks may be voice-frequency or carrier. The termination at the class 5 office is two-wire; at the higher class offices it may be two-wire or four-wire, depending on the switching machine.

The toll switching network is provided with intertoll trunks between various combinations of office classes. One such combination is shown in Figure 1-3. Note that final trunk groups (i.e., those carrying traffic for which they are the only route and overflow traffic for which they are the "last choice" route) are provided between each lower ranking office and the higher ranking office on which it homes. All regional centers are interconnected by final trunk groups. High-usage trunk groups, which provide for alternate routing, are installed between any two offices that have sufficient community of interest. Automatic switching of toll circuits facilitates the use of alternate routing, so that a number of small loads may be concentrated into large trunk groups, resulting in higher efficiencies and attendant economies.

The order of choice of trunks for a call originating in end office 1 and terminating in end office 2 is indicated in Figure 1-3 by the numbers in parentheses. In the example there are ten possible routes for the call. Note that the first choice route involves two intermediate links. In many cases a single direct link, which would be first choice, exists between the two toll centers. Only one route requires seven intermediate links (intertoll trunks in tandem), the maximum permitted in the design of the network.

The probability that a call will require more than n links in tandem to reach its destination decreases rapidly as n increases from 2 to 7. First, a large majority of toll calls are between end offices associated with the same regional center. The maximum number of toll trunks in these connections is therefore less than seven. Second, even a call between telephones associated with different regional centers is routed over the maximum of seven intermediate toll links only when all of the normally available high-usage trunk groups are busy. The probability of this happening in the case illustrated in Figure 1-3 is only p^5, where p is the probability that all trunks in any one high-usage group are busy. Finally, many calls originate above the base of the hierarchy since each higher class of office incorporates the functions of lower class toll offices and usually has some class 5 offices homing on it. Figure 1-5 makes these points more specific. The middle column of this table shows, for the hypothetical system

NUMBER OF INTERMEDIATE LINKS, n	PROBABILITY	
	FIGURE 1-3	1961 STUDY
Exactly 1	0.0	0.50
2 or more	1.0	0.50
Exactly 2	0.9	0.30
3 or more	0.1	0.20
4 or more	0.1	0.06
5 or more	0.0109	0.01
6 or more	0.00109	0
Exactly 7	0.00001	0

Figure 1-5. Probability that n or more links will be required to complete a toll call.

of Figure 1-3, the probability that the completion of a toll call will require n or more links between toll centers, for values of n from 1 to 7. In computing probabilities for this illustration, the assumptions are: (1) the chance that all trunks in any one high-usage group are simultaneously busy is 0.1; (2) the solid line routes are always available; and (3) of the available routes the one with the fewest links will always be selected. The values in Figure 1-5 illustrate that connections requiring more and more links become increasingly unlikely. These numbers are, of course, highly idealized and simplified.

Actual figures from a Bell System study made in 1961 are shown in the last column of the table of Figure 1-5. These numbers represent the probability of encountering n links in a completed toll call between an office near White Plains, New York, and an office in the Sacramento, California, region. The assumption was made that all traffic had alternate routing available and that blocking due to final groups was negligible. Note that at that time 50 percent of the calls were completed over only one intermediate link. This is not possible in the layout shown in Figure 1-3, where it may be assumed that traffic volume does not yet justify a direct trunk between toll centers. The maximum number of links involved in the 1961 study was five; this number was required on only 1 percent of the calls.

More recent studies, reported informally, indicate that the trend continues in the direction of involving fewer trunk links in toll calls. In 1970, approximately 75 percent of all toll calls were completed over only one intertoll trunk; 20 percent required two intertoll trunks in tandem; about 4 percent required three trunks; the remaining 1 percent required four or more intertoll trunks in tandem. This trend is a result of increasing connectivity between offices by providing increased numbers of high-usage trunk groups (direct connections) between lower classes of offices in the hierarchy.

1-3 IMPACT OF SYSTEM MULTIPLICITY ON NETWORK PERFORMANCE

The provision of customer-to-customer communications channels can involve a multiplicity of instrumentalities, facilities, and systems interconnected in many ways. Station sets, loops, and end offices are

particularly important, especially in the switched message network, since they are used in every connection. Toll connecting and intertoll trunks, toll transmission systems, and toll switching machines are also important when communications beyond the local area are considered. The overall comprises a complex configuration of plant items whose interactions give rise to several broad problems in the total network design and operation.

The first problem is that the accumulation of performance imperfections (such as loss, noise, and impedance irregularities) from a large number of systems leads to severe requirements on individual units and to great concern with the mechanisms causing imperfections and with the ways in which imperfections accumulate.

The second problem is that the variable complement of systems forming overall connections makes quite complex the problem of economically allocating tolerable imperfections among these systems. Deriving objectives for a connection of fixed length and composition is a problem involving customer reactions and economics. However, when these objectives must be met for connections of widely varying length and composition, the problem of deriving objectives for a particular system requires an even more complex statistical study involving considerable knowledge of plant layout, operating procedures, and the performance of other systems.

A third problem involves the satisfactory operation of each part with nearly all other parts. Compatibility is particularly important when new equipment and new systems are being developed, because the existing plant and the new interact importantly in many ways and also because plant growth must take place by gradual additions rather than by massive junking and replacement.

A fourth problem is that of reliability. Only small percentages of outage time are acceptable for the communications services provided by the Bell System, and these must account for all causes of failure—equipment failure, natural or man-made disaster, operating errors, etc.

Finally, to be complete, any discussion of the environment must recognize that telephone plant and power transmission and distribution systems share the same geography, either aerially or under-

ground. This fact is important from a safety standpoint and from the standpoint of quality of transmission on telephone facilities. Power systems may come in contact with telephone plant as a result of storms, plant failures, or induction, endangering customers, employees, and property unless protective measures are applied. The presence of power systems in proximity to the telephone plant can also be damaging from the standpoint of quality of telephone transmission since noise induction is a distinct possibility.

1-4 MAINTENANCE AND MAINTENANCE SUPPORT

The switching patterns that have been described impose strict requirements on all transmission circuits. For example, up to seven intertoll trunks may be connected in tandem, and successive calls between the same two telephones may take different routes which involve different numbers and kinds of circuits. The losses encountered on calls routed over different numbers of links must not vary excessively, nor may the transmission quality vary significantly. If unsatisfactory transmission occurs, it cannot be observed by an operator as in the past, and the customer's attempt to report the trouble disconnects the impaired circuit, making difficult the identification of the source of trouble.

To cope with this situation, many central offices have extensive test facilities associated with them. Some of these facilities are test switchboards which have access to the lines and trunks in the office by manual patch or cross-connecting means. New automatic test facilities are also now available and are used extensively to test interoffice trunks by way of special trunk circuits and access arrangements provided in the switching machines. In addition, many central offices are equipped with voiceband data test centers for both DATA-PHONE® and private line service.

A great variety of portable, special purpose, and general purpose test equipment is also usually available in most central offices. This equipment, fixed and portable, manual and automatic, is described in greater detail later.

Extensive test equipment is also available for special services. For example, test equipment for television and wideband data services is

located at the Television Operating Centers and the Wideband Data Test and Service Bays.

In addition to equipment that is directly involved in maintenance, there is an extensive list of equipment and transmission system features that may be classified as maintenance support. These equipment and service features are designed to facilitate trouble identification, isolation, and repair, to prevent extensive proliferation of trouble conditions, to provide for emergency restoration of broadband facilities on a temporary basis, to provide for remote telemetering and remote control of maintenance equipment and alarms, and to provide special communications channels (order wires) for maintenance personnel. These also are described in greater detail in a later chapter.

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2. Bell System Technical Reference PUB41005, *Data Communications Using the Switched Telecommunications Network* (American Telephone and Telegraph Company, August 1970).
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Chapter 2

Introduction To Transmission

The movement of intelligence from one point to another is the basic task of the Bell System. The intelligence to be moved can be called a *message,* regardless of the form it takes or its purpose. The most common form, of course, is speech, and the telephone system was initially developed around the need for voice communications. Over the years, however, many other types of messages (such as facsimile, program, video, and data) have evolved.

In general, transmission technology has advanced in parallel with this evolution, providing a means of translating these messages into electrical signals and developing the communications channels that make it possible to transmit the messages in reversible form via existing transmission media. Extension of the capabilities of the existing multiple-link plant and the development of new plant compatible with the old and capable of fulfilling transmission requirements are among the problems confronting the transmission engineer.

The variety of message signals and types of channels interact in many ways. Different types of message signals require channels of various bandwidths and operating characteristics. These channels utilize voice-frequency and carrier facilities which must meet stringent requirements if they are to provide satisfactory service economically. To meet these requirements, it is sometimes necessary to use specially designed ancillary equipment on the channels or systems.

2-1 MESSAGE SIGNALS

The characterization of transmitted message signals is essential to an understanding of how such signals interact with the channels over which they are transmitted. The *message signal* is defined as

an electrical representation of a message, which can be transmitted in its electrical form from source to destination. Qualitative descriptions of the more common signals found in the Bell System are given here. The signals described in this chapter include voice, program, video, data and facsimile, and control signals. The latter, usually classified as signalling and supervision, are transmitted in order to activate switching operations and to perform other subsidiary functions. Variations of these signal types are used to transmit all messages presently offered as Bell System communication services. Any of the signals may be transmitted in either digital or analog form; the choice is dependent in some cases on the transmission facilities available. More detailed quantitative characterizations of all these signal types are given in Chapters 12 through 16.

Speech

The most common signal transmitted over Bell System facilities is the speech signal, an electrical signal generated in the telephone station set as an analog of the acoustical speech wave generated in the voice box, or larynx, of the speaking telephone user. This signal carries most of its information in a band of frequencies between 200 Hz and 3500 Hz. Most of the energy is peaked near 800 Hz; most of the articulation is above 800 Hz. It has higher frequency and lower frequency components, but these are not normally transmitted. It is an extremely complex signal, not only because of the large number of frequency components it contains, but also because of the wide range of amplitudes that any component may have and because of the rapidity with which the frequency and amplitude of its components may change.

Another complexity is the time relationships inherent in the speech signal. By one definition or criterion, the signal duration might be measured from the time the connection is established until it is broken. By another criterion, the signal duration might be defined as the speaking interval—during a typical telephone connection, each party speaks about half the time and listens the other half. But the situation is even more complex. There are short intervals, sometimes only milliseconds in length, during which a speaker pauses for breath or for other reasons. Signal duration could be defined as covering the time between those pauses. So, it is a matter of definition; care

These return losses are measured against standard terminations, the values of which depend on the type of switching office involved. The measurement process and the complexity of impedance adjustment procedures that permit these return loss objectives to be met have led to the expression of objectives in terms of through balance and terminal balance requirements applied for many types of trunks at various types of toll switching offices.

Echo return loss objectives have less influence in the design of local trunks than in the design of toll trunks because echo problems are negligible for short trunk lengths. The objectives for singing return loss on these trunks are not firmly established, but the return losses are usually held to about 10 dB.

Loss Objectives

The echo path loss involved in determining echo amplitude is made up of the return loss and twice the circuit loss between the speaker and the point of reflection. These circuit losses must be well controlled; they must be low enough to satisfy the requirements on talker volume and to avoid excessive contrast in volume from call to call yet they must be high enough to attenuate echoes to tolerable values.

Volume. The basic problem in telephone transmission is to provide a satisfactory signal amplitude at the receiver. The received signal amplitude is a function of many interacting parameters, starting with the transmitted signal amplitude. The latter depends on telephone speaking habits, station set efficiency of conversion from acoustic to electric signal energy, sidetone circuit design of the station set, and losses in the circuits between the transmitter and the receiver.

Received volume differs from many other quality parameters in that its effects are double-ended; volume can either be too low, causing difficulty in understanding the received message; or it can be too high, causing listener discomfort. Subjective tests have been made to determine listener reactions to different volumes. The results of one series of such tests, plotted in Figure 26-3, clearly show the double-ended nature of this parameter. Volumes to the left of the two left-hand curves are judged to be too low to satisfy listeners while volumes to the right of the right-hand curve are too high to satisfy listeners. Each of the curves, which divide regions of volume rated poor, fair, good, etc., is approximately normal with a standard

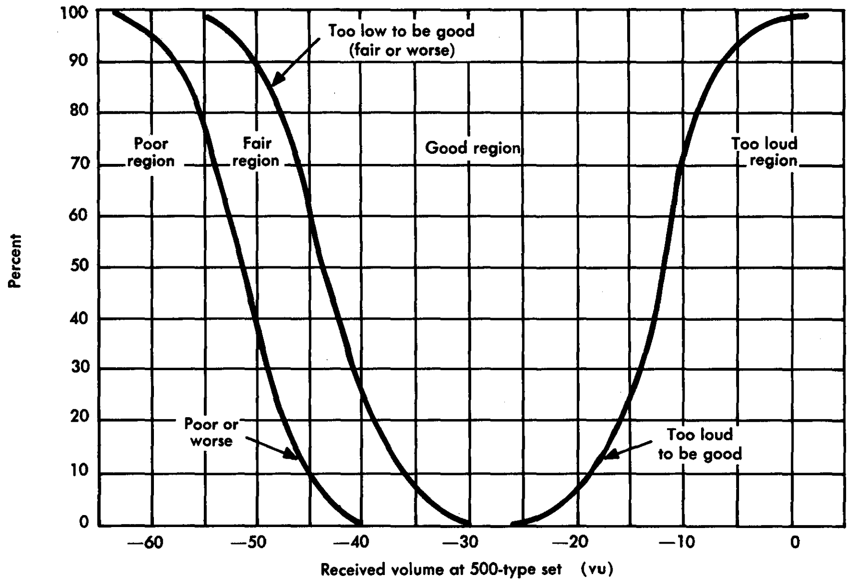

Figure 26-3. Judgment of received volume from subjective tests.

deviation of about 5 dB. The curves show a fairly wide range (from about —43 vu to about —12 vu at the median values) over which received volumes are rated good.

Data of the type shown in Figure 26-3 have been used to help establish allowable circuit losses in end-to-end customer connections. The total loss allowance is allocated to the various parts of the plant in accordance with the results of economic studies and with a satisfactory noise-loss-echo grade of service established by subjective testing.

Loss Allocations. Transmission objectives for loop loss have been derived on the basis of satisfying an overall loss/noise grade-of-service objective [3, 6]. Control of loop loss is accomplished by the application of carefully specified rules in the design and layout that produce a satisfactory distribution of losses. The three sets of rules are parts of the *resistance, unigauge,* and *long route design* plans. These three design plans permit straightforward application of the

rules to the installation of new cables, of inductive loading, and of electronic equipment so that overall loss objectives are met because the objectives are built-in, integral parts of the plans. When the plans are properly applied, the resulting distribution of loop losses has a maximum value of about 9 dB (including the effects of bridged taps). The mean value and the standard deviation of the loss distribution depend on the geographical area served and on the concentration of customers within the area. For the Bell System, an average 1000-Hz value of 3.8 dB and a standard deviation of 2.3 dB are typical; these values are used in the determination of network loss objectives and grade of service.

The above values of loop losses were determined on the basis of measurements made in 1960 and 1964 [5]. Subsequent studies of losses and grade-of-service objectives resulted in some tightening of the objectives, particularly in the long route design plan.

Since a numerical loss objective (other than the maximum) is not expressed for individual loops, special treatment must be applied (1) when a loop is assigned to data transmission or another special service need and (2) when transmission complaints still exist after it has been verified that the loops involved have been installed according to appropriate design procedures.

Loss objectives for transmission circuits through switching machines have not been firmly established, but a loss of less than 1 dB is generally allowed for these circuits. Losses of various types of trunks constitute the remaining major allocation to parts of the plant, and for purposes of network administration, trunk losses are now defined in such a way as to include average switching system loss. Many of the loss values are given in terms of via net loss which varies according to the length and type of facility.

Losses allocated to trunks depend on the position of the trunk type in the switching hierarchy and the probability of encountering tandem connections of such trunks in an end-to-end telephone connection. In the toll portion of the network, interregional intertoll trunks are designed on the basis of maximum round-trip echo delay that can occur on connections involving the interregional trunks. If the delay can exceed 45 milliseconds, the interregional trunks are equipped with echo suppressors and the trunks are operated at 0 to 0.5 dB loss. (Losses high enough to satisfy echo requirements would generally be

too high to satisfy volume and contrast objectives.) If the round-trip echo delays are less than 45 milliseconds, the interregional trunks are operated at VNL, with a maximum of 2.9 dB.

High-usage intertoll trunk groups are operated at via net loss where the value of loss is VNL $\leqq$ 2.9 dB, equivalent to a maximum trunk length of about 1850 miles on carrier facilities. If echo requirements call for a loss greater than 2.9 dB, the trunks are operated at 0 dB loss and are equipped with echo suppressors unless they are in a final routing chain. To avoid having more than one echo suppressor in a connection, echo suppressors are generally permitted only in final groups between regional centers. Secondary intertoll trunks are operated as close to 0 dB as possible, with a maximum of 0.5 dB. Final intertoll trunk groups are operated at via net loss, but at a maximum of 1.4 dB loss.

Toll connecting trunks are usually operated at VNL + 2.5 dB loss with a maximum loss of 4.0 dB. An alternate design allows a trunk to have 3.0 dB to 4.0 dB loss provided it contains less than 15 miles of VF cable facilities or less than 200 miles of carrier facilities. On long end-office trunks (usually interregional) between class 4 and class 5 offices where echo requirements indicate the need for loss greater than 4 dB, an echo suppressor may be added and the loss set at 3 dB.

In the local portion of the network, direct trunks are designed to a nominal loss of 3 dB with a maximum of 5 dB. Tandem trunks are operated at a nominal loss of 3 dB and a maximum of 4 dB, and intertandem trunks are operated at via net loss. Loss values are assigned similarly to all service and miscellaneous trunks used in the network. Long interregional direct trunks (between class 5 offices) may be operated without echo suppressors at VNL + 6 dB loss (maximum 8.9 dB) over distances of up to 4000 miles.

Loss Maintenance Limits

In order to maintain network performance, 1000-Hz measurements of trunk losses are made periodically in accordance with maintenance programs described in Volume 3. The objectives are set in accordance with indices which have been derived in relation to grade-of-service objectives. The percentage of measurements showing deviations from design values in excess of 0.7 or 1.7 dB (the larger deviations carry

heavier weighting) determines the index for the group of trunks under study. If the index is 96 or higher, performance is satisfactory and no action is necessary. If the index is below 96, investigation and corrective action are indicated. If the loss of any trunk deviates from its design value by 3.7 dB or more, it must be removed from service.

Message Circuit Noise

Message circuit noise is defined as the short-term average noise measured by means of a 3A noise measuring set or its equivalent [7]. Objectives for message circuit noise, allocated to various parts of the network, are based on subjective tests in which noise was evaluated by telephone listeners in the presence of speech signals held at a constant volume. Noise and volume were expressed in dBrnc and vu, respectively, at the line terminals of the station set; observers were asked to rate the performance in the usual manner (excellent, good, fair, poor, or unsatisfactory) for a wide range of noise values. The results of these tests are shown in Figure 26-4.

Loop Noise Objectives. The message circuit noise objective applied to loops is that noise measured at the line terminals of the station set shall not exceed 20 dBrnc.* Noise at or below this value has little effect on grade of service, but noise in excess of 20 dBrnc deteriorates grade of service appreciably.

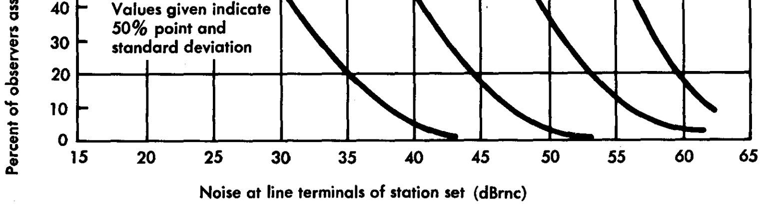

Figure 26-4. Noise opinion curves.

* Most loops have measured noise well below this value. The average is about 0 dBrnc.

In recognition of the special circumstances relating to long routes (those in excess of 1300 ohms controlled by resistance design and those extended by the unigauge design, both discussed in Volume 3), the noise objective is made somewhat more lenient. For long routes the noise objective is administered at 30 dBrnc. For routes on which the limit of 30 dBrnc is exceeded, special treatment (shielding, separation from power lines, balancing, etc.) must be employed according to circumstances.

Trunk Noise Objectives. The performance objectives for trunk noise have been allocated to allow for the tendency of noise to accumulate with distance and the smaller number of calls of very long distances compared with intermediate and short distances. To give weighting to these two factors, trunk noise objectives have been selected to achieve a 99 percent good-or-better grade of service for short toll connections (0 to 180 miles, airline distance), 97 percent good or better for medium length toll connections (180 to 720 miles), and 95 percent good or better for long toll connections (over 720 miles). Consistent with these overall objectives, allocations have been made for short-haul carrier facilities (for use on trunks less than 250 miles long), and long-haul carrier facilities (for use on trunks over 250 miles long). These allocations, which recognize the inherent variability of performance in the field environment, are expressed in terms of mean values and standard deviations. For short-haul carrier, the mean value of the objective is 28 dBrnc0 at 60 route miles and for long-haul carrier, 34 dBrnc0 at 1000 route miles. The standard deviation is $\sigma = 4$ dB in each case. These allocations allow for a 3 dB increase in noise for each doubling of the distance. This increase is typical of analog carrier system performance but is not usually experienced in pulse-type carrier systems. Design objectives for carrier systems are based on these performance objectives but are normally expressed in terms of worst channel noise in a nominal environment. The current design objective for 4000-mile coaxial cable systems, including multiplex equipment, is 40 dBrnc0. The design objective for microwave radio systems is approximately 1 dB higher [3]. Generally, where these message circuit noise objectives are met for speech transmission, objectives for voiceband data transmission are also met.

Impulse Noise

Impulse noise is any burst of noise that produces a voltage in excess of about 12 dB above the rms noise as measured by a 3-type

noise measuring set with C-message weighting; in a speech channel, these bursts are usually less than 5 but may very rarely be as long as 45 or 50 milliseconds in duration. The ratio of the voltage excess to the rms noise voltage is nominally at least 12 dB for a 3-kHz bandwidth; it may be as great as 40 dB in some systems, particularly microwave radio. Impulse noise is usually viewed as superimposed on background message circuit noise [8]. Objectives are dominated by requirements for digital data signal transmission, and circuits that are satisfactory for data are generally satisfactory for speech signal transmission.

Impulse noise objectives are usually established on the basis of the number of counts obtained on a 6-type impulse noise counter during a prescribed measurement interval and may be expressed for loops, trunks, or customer-to-customer connections. The application of acceptable objectives to station sets and central office equipment is under study.

The objective for any loop or single voice channel is that there should be no more than 15 impulse noise counts in 15 minutes at a given threshold. For a sampled trunk group, there should be a maximum of 5 counts in 5 minutes at a given threshold. Sampling plans are specified and the noise thresholds are set at different values for loops, for VF trunks, and for compandored and noncompandored carrier trunks. The threshold values are also weighted to take into account the expected increase of noise with distance in carrier systems. The trunk impulse noise thresholds are shown in Figure 26-5. The loop impulse noise threshold is 50 dBrnC referred to the local central office.

Intelligible Crosstalk

Intelligible crosstalk objectives are generally expressed in terms of the crosstalk index, a measure of the probability of receiving intelligible crosstalk. The derivation of the crosstalk index, its relationship to the impairing effects of intelligible crosstalk, and the use of generalized crosstalk index charts are presented in Chapter 17.

Objectives have been established for most types of trunks. A maximum crosstalk index of 1 is used for intertoll and secondary intertoll trunks. An index of 0.5 is applied to toll connecting, direct, tandem, and intertandem trunks. No index objective has yet been established for loops.

FACILITY TYPE			
TRUNK LENGTH (MILES)	VF TRUNKS, dBrnc0	COMPANDORED* CARRIER AND MIXED COMPANDORED-NONCOMPANDORED, dBrnc0	NONCOMPANDORED CARRIER, dBrnc0
0-60	54	68	58
60-125	54	68	58
125-250	54	68	59
250-500		68	59
500-1000		68	59
1000-2000		68	61
over 2000		68	64

* Compandored trunks, including those with D-type channel banks, are measured with a -10 dBm0 tone transmitted from the far end and filtered out ahead of the measuring set by a C-notched filter or equivalent. The C-notched filter is a C-message weighting network with a narrowband suppression section to provide at least 30 dB of attenuation at the tone frequency.

Figure 26-5. Impulse noise thresholds for trunks.

Crosstalk objectives for central office equipment are usually expressed in terms of equal level coupling loss. In four-wire offices, the objective for minimum coupling loss between the two sides of one circuit is 65 dB. The coupling objective for different circuits is 80 dB in two-wire and four-wire offices.

Single-Frequency Interference

Well documented and generally accepted transmission objectives for single-frequency interferences are not now available. When new systems have been designed, design objectives have been applied in a generally conservative manner. The factors that have made it difficult to derive acceptable objectives include the frequency and amplitude of the interference, the stability or variability of frequency and amplitude, the harmonic content of the interference, the presence or absence of masking message circuit noise or other interferences, the possible presence of other single frequencies, and the constancy or intermittency of the interference. As a rule of thumb, single-frequency interferences must be well below other noise in the circuit.

The most conservative estimate, one that makes single-frequency noise inaudible to nearly everyone, is that the interference should be 30 dB below message circuit noise. More lenient estimates have led to design objectives of 10 to 12 dB below message circuit noise. These objectives apply to speech signal transmission and, when met, usually result in satisfactory transmission of other voiceband signals.

Frequency Offset

Frequency offset objectives are set primarily to satisfy the needs of program signal transmission. While the determination of the threshold for frequency offset is as critical to speech transmission as it is to music transmission, subjective tests have shown that listeners are more tolerant of offset in speech signals than in music signals. The overall performance objective for offset is a maximum value of $\pm$ 2 Hz; the maintenance objective is $\pm$ 5 Hz.

Overload

Overload of broadband or single-channel electronic systems produces signal impairments in the form of noise and distortion. The objective for overload is expressed as a degradation of the grade of service in an individual channel. While objectives have not been firmly established, a reduction of about 1 percent in good-or-better and an increase of about 0.1 percent in poor-or-worse grades of service appear to be reasonable performance objectives for the overload phenomenon. These criteria, when applied to D-type channel banks used with T-type carrier systems, have resulted in the objective that these banks transmit a +3 dBm0 sine wave signal without causing overload impairment.

A signal transmitted at higher amplitude than the design value may cause intelligible crosstalk or single-frequency tone interference as a result of intermodulation or other crosstalk paths. This impairment is not considered as overload unless it is so extreme that the entire system is affected.

Miscellaneous Impairments

A number of miscellaneous impairments are recognized as having potentially serious degrading effects on voice-frequency channel transmission; they include phase and gain hits, phase and gain jitter, incidental frequency modulation, and dropouts. Formal objectives for these types of impairments have not been established.

Telephone Station Sets

The transmission performance of station sets is controlled primarily by design, and there are no specific transmission performance or maintenance objectives. The great majority of sets in service are the 500-type, which were developed to meet a set of stringent design objectives [9]. There are no transmission options or adjustments on these sets. Therefore, where troubles can be identified with the station set or where trouble complaints cannot be identified with other parts of the local connection, the transmitter, the receiver, or the entire set may be replaced and returned to the manufacturer.

A unique consideration is involved in operator and auxiliary services wherein the operator headset (receiver and microphone) must be regarded as the station set. One of the more stringent objectives that must be met by these circuits is that pertaining to sidetone. In this case, sidetone is a design parameter of the access circuits rather than the headset circuits. The objectives are commonly expressed in terms of the acoustic sidetone path loss, which is defined as the ratio in dB of the loudness-weighted acoustic sound pressure produced by the receiver for a given loudness-weighted acoustic sound pressure input to the transmitter (or microphone). The objective for this loss is 12 dB, an optimum determined by subjective tests; values as low as 8 dB and as high as 16 dB are considered tolerable.

26-2 WIDEBAND DIGITAL SIGNAL TRANSMISSION OBJECTIVES

As in the case of transmission objectives for voice-frequency channels, the expanding use of existing channels for new types of signals and services has made it necessary to refine and redefine channel transmission objectives. Similarly, the adaptation of analog systems and portions of analog systems for wideband digital signal transmission has led to new objectives for wideband channel applications. Frequency bands that were originally provided only as parts of the voice transmission network are being adapted for wideband digital signal transmission, and as a result, transmission objectives for the wider bands and new signals are in process of refinement and redefinition. In addition, digital transmission systems are being developed and introduced into the network, thereby requiring that objectives be established for their design and operation.

The transmission objectives to be established and the manner of adapting systems and signals for compatibility depend on the signal format, the sensitivity of the signal to various impairments, and the characteristics of the system or channel involved. The parameters involved include load capacity, bandwidth, signal-to-noise performance, jitter, error rates, and the rate of digital transmission.

The wide range of bandwidths, signal formats, impairments, services, and digital systems makes it difficult to present a complete set of wideband digital transmission objectives. Therefore, this discussion is limited to a number of examples of objectives that have been established for specific signal formats and to the approach used in several digital system designs. In most cases, the determination of the objective ultimately rests on subjective judgment of the required grade of service.

There are two types of wideband digital signals commonly transmitted on analog systems: the 1A Radio Digital System (1A-RDS) signal, a 1.544 Mb/s signal transmitted at baseband (0 through 500 kHz) over microwave radio systems in a multilevel signal format containing seven discrete levels and a family of binary digital data signals that may be transmitted at 19.2 kb/s, 50.0 kb/s, or 230.4 kb/s in the half-group, group, or supergroup bands, respectively, of the L-multiplex (FDM) equipment [10, 11]. Transmission objectives for these signals and for digital transmission systems are evolving as the technology advances.

Performance Evaluation

Transmission objectives for wideband digital signals are expressed variously in terms of error rate, noise impairment, and eye diagram parameters. In addition, objectives must be expressed for signal power when digital signals are to be transmitted on analog systems.

Error Rate. A commonly used design objective for wideband digital signal transmission, one that has not been sanctioned for general application, is an error rate of 10^{-6}; i.e., the terminal-to-terminal

error rate shall not exceed one error in 10^6 bits. Error rate counters, or violation counters as they are sometimes more properly called, are used with many systems to determine error performance for the complete end-to-end connection or for some link in the connection. Violations of a predetermined code format are counted and compared with the objective which must be expressed in the same terms. The objective must be that value allocated to the particular link under surveillance.

Noise Impairment. The expression of an objective in terms of noise impairment is used to equate the degradation of channel performance by various impairments to an equivalent degradation due to Gaussian noise. This equivalence can be explained in another way. A certain error rate can be expected from a given channel whose characteristics are ideal in all respects except for the presence of Gaussian noise. The noise impairment due to the introduction of some other degradation, such as delay distortion, is measured by the improvement in Gaussian noise (improved signal-to-noise ratio) that would be required for the same channel performance as in the channel impaired only by the original value of Gaussian noise.

Two goals are met by expressing objectives in terms of noise impairment. First, objectives can be allocated to a variety of impairments in an orderly manner that lends itself readily to changes necessary to meet specific conditions. Second, a straightforward method is provided for determining how good the channel signal-to-noise ratio must be to meet a specified error rate objective. Both advantages are especially desirable for studies of digital signal transmission on analog channels.

Eye Diagram Closure. When a random stream of digital pulses is properly impressed on an oscilloscope, the successive pulses can be made to form a pattern, called an eye diagram. As the pulse stream is impaired by channel imperfections (such as noise, gain and delay distortion, and crosstalk), the opening in the eye (or eyes for multilevel signals) is reduced by predictable amounts. Thus, the eye pattern may be used as a measure for performance, and transmission objectives can be expressed in terms of the percentage of eye closure.

This manner of stating objectives has not proved to be useful in operating and maintaining systems, but it has found considerable use in system design where measurements are made under laboratory

conditions [12, 13]. The approach has been used to compare performance and objectives; it has also been used as a means of allocating objectives among a number of different impairments, each being allowed a certain percentage of eye closure in the horizontal (timing) or vertical (amplitude) dimensions or in both.

Signal Power. When a signal is impressed upon a transmission channel, the channel must be capable of transmitting the signal satisfactorily; in addition, the signal cannot be allowed to degrade other signals that may share the same transmission system. Overload performance is one criterion that must be satisfied in both respects.

The impressed signal amplitude must be limited so that the signal itself is not degraded by the overload characteristics of the channel. The degradation would fall between two extremes, one in the form of peak clipping that might be relatively innocuous and the other in the form of excessive distortion that would render the signal useless. The limiting value depends in each case on the characteristics of the channel or system to be used.

Simultaneous transmission of digital and other kinds of signals on analog facilities further requires that the load imposed by the digital signals does not seriously impair the other signals. The usual criteria for the loading objective are (1) that the average power in the digital signal shall not exceed the average power allotted to the displaced speech channels (—16 dBm0 per 4-kHz band), and (2) that any single-frequency component of the digital signal shall not exceed —14 dBm0. The latter criterion is sometimes relaxed if the component is not a multiple of 4 kHz or if the amplitude variability results in a low probabiilty of its exceeding —14 dBm0.

Design Applications

Since most transmission objectives for wideband digital signals have not yet been formally accepted or generally applied, it is best to illustrate for specific cases the ways objectives evolve, are derived, and are applied.

Bit Rate and Bandwidth. In the design of a new digital transmission system or the adaptation of analog facilities to the transmission of digital signals, the first consideration is the overall system design problem of relating available bandwidth to the desired transmission rate. First-order effects on the design include: (1) the achievable

signal-to-noise ratio of the proposed facility, (2) the desirability of designing a synchronous system that permits regeneration, (3) the cost involved in terminal and signal regeneration equipment, (4) the feasibility and cost of equalizing the medium, and (5) the transmission objectives that must be satisfied if the service needs are to be met. While the concern here is primarily with the objectives, all of these effects interact in ways that make discussion of objectives meaningless unless the interactions are explored as well.

The need for digital signal transmission over the analog microwave radio network evolved partly from the Digital Data System (DDS) development program. The feasibility of transmitting a DS-1 signal on a TD-type radio system was established but this possibility was deemed undesirable because the DS-1 signal carries significant energy at frequencies up to 1.544 MHz. A substantial number of telephone channels would thus have to be dropped to accommodate the digital signal. It was also shown that the upper half of the DS-1 spectrum might be filtered or the signal might be coded as a 3-level, class IV, partial response signal with spectral nulls at 0 and 772 kHz. The former approach was more theoretical than practical; the latter still appeared too costly because about 120 message channels would have to be dropped to provide a roll-off band.

A 7-level, class IV, partial response signal with a 15 percent roll-off band was chosen and is now used in the 1A Radio Digital System (1A-RDS) which provides a digital facility for DDS. The signal has spectral nulls at 0 and 386 kHz and extends only to 444 kHz, well below the 564-kHz multiplex low-end frequency. Thus, no message channels are displaced.

Performance Objectives. Objectives for 1A-RDS were derived from those established for DDS. They were based on a level of performance which was judged would provide a high-quality service at the customer sub-rates of 56 kb/s and below. The basic criterion was stated in terms of percentage of error-free seconds. Allowances were included for known sources of hits, such as those caused by protection switching initiated by maintenance activities and fading. A sub-set of objectives covers the number of errored-seconds that occur in shorter periods of time and the number and length of error bursts.

Designs Based on Noise Impairments. In setting objectives for transmitting wideband digital data signals in the half-group, group, and supergroup bands of the L multiplex equipment, a major concern was the equalization of gain and delay distortion in those bands. The objectives for these services were derived initially from the basic goal of achieving an error rate of 10^{-6} or better (between terminals) 95 percent of the time. Portions of this objective were then allocated to various well-defined impairments (random and impulse noise, for example), and the remainder was allocated to misequalization, data set and terminal limitations, net loss variations, and jitter.

These allocations first involved the derivation of a required signal-to-noise ratio of 12.7 dB. After noise impairments had been assigned to each of the principal sources of degradation anticipated, it was concluded that an overall signal-to-noise ratio (Gaussian noise) of 22 dB would be required to meet the service objective; this signal-to-noise ratio was used as a design objective.

26-3 VIDEO TRANSMISSION OBJECTIVES

The Bell System transmits three types of video signals that might be reviewed in detail in terms of applicable transmission objectives: broadcast television signals, closed circuit television signals, and PICTUREPHONE signals. Only broadcast television signals are covered, however, since closed circuit television and PICTUREPHONE objectives are not well established. Generally, closed circuit television objectives tend to be somewhat more lenient than those for broadcast quality signals. Thus, it is usually safe to use broadcast objectives; if there appears to be serious difficulty in meeting them, the case must be considered separately. For PICTUREPHONE, only some early design objectives have been used in preliminary studies and experimental work [14].

The objectives to be discussed are, for the most part, expressed in terms of overall 4000-mile objectives. These, of course, must be allocated to different parts of the plant in accordance with some logical procedure, as outlined in Chapter 25. Most of the objectives given are design objectives, and each must be interpreted carefully and applied judiciously when operational variations and limits are considered for use as performance and maintenance objectives.

Random Noise

The degree of noise impairment to television signals is a complex function of the distribution of noise power versus frequency and the characteristics of the impaired signal (for example, whether it is a

monochrome or a color signal). When the noise is at a high enough amplitude, it may appear as fine, closely packed dots in rapid, random motion. When observed in monochrome signal transmission, the dots appear to have the characteristics of a swirling snowstorm; as a result, the impairment has commonly been referred to as "snow."

If the noise is concentrated at the lower video frequencies, the dots are relatively large or may appear as streaks in the picture. If the noise is concentrated at high frequencies, the dots are much finer and harder to see. Hence, equal powers of noise are judged to be more annoying at low than at high frequencies. When the noise is concentrated in relatively narrow bands, it produces fleeting herringbone patterns in the received pictures. If the band is made narrower, the pattern approaches that of a single-frequency interference. Thus, equal powers of noise tend to be more objectionable as the bandwidth of the noise is decreased.

These observations have led to the expression of random noise objectives in terms of a single weighted value applicable to monochrome or color signals. The weighting, which takes into account the more objectionable nature of low-frequency noise, makes possible the use of a single number as an objective; i.e., equal measured values mean equal subjective effects, regardless of the type of noise. The effect of narrowband noise is accounted for simply by weighting its effect with that of broadband noise on the basis of total power. Thus, if single-frequency interference is present in a channel, the random noise objective must be made more stringent by an amount that makes the power sum of random and single-frequency noises meet the random noise objective. In addition, the single-frequency objective must also be met.

The random noise weighting characteristic is shown in Figure 26-6. In spite of some differences in annoying effects in monochrome and color signal transmission, it is found that satisfactory results are obtained when this single weighting curve is used to evaluate noise on facilities used for both types of signals [15]. The objective generally applied is that the noise introduced by a 4000-mile system produce a signal-to-noise ratio of 53 dB or better. This ratio is expressed in terms of the peak-to-peak composite signal voltage (including synchronizing pulses) to the weighted rms noise voltage in the frequency range of 4 kHz to 4.2 MHz. The noise from zero to 4 kHz is treated separately.

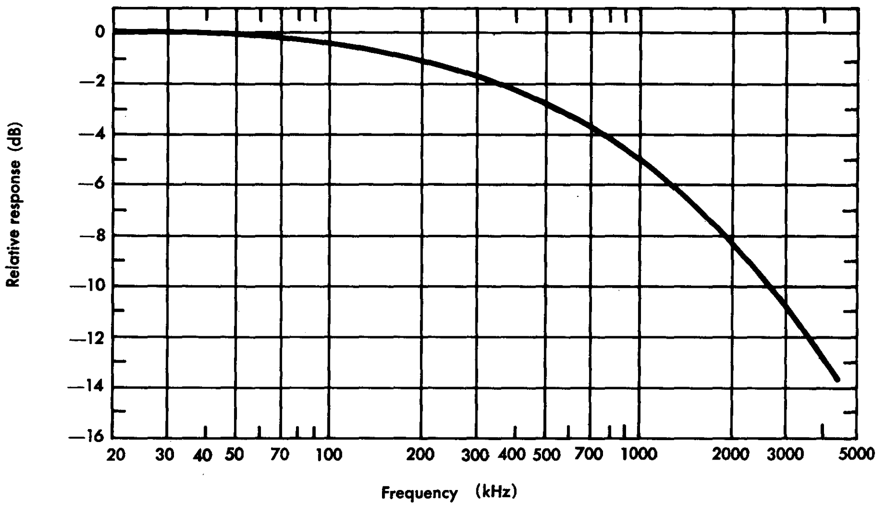

Figure 26-6. Monochrome and color random noise weighting for broadcast television signals.

Low-Frequency Noise

Noise in the band from zero to 4 kHz is measured in a manner similar to that for random noise. It is treated separately because of the likely presence of power-frequency interference (hum in telephone circuits), which can cause bar pattern interference in the received picture. If hum is not present, the low-frequency random noise is simply added to the broadband random noise.

The objective for low-frequency interference is expressed in terms of the ratio of the peak-to-peak signal voltage to the rms interference voltage in the band from 0 to 4 kHz. The objective for a 4000-mile circuit is a 50 dB signal-to-noise ratio.

Impulse Noise

The characteristics of impulse noise are not well-defined for evaluation as a television impairment. Generally, impulse noise is any interference that affects a small portion of the received picture for only a short interval of time.

The objectives for impulse noise are also not well-defined. A ratio of the peak-to-peak composite signal voltage to the peak impulse

voltage of 20 dB is sometimes considered to be an acceptable objective. It is applied specifically to interferences that occur at a rate of about one per minute. No quantitative data are available for impulses of different durations or for other frequencies of occurrence.

Single-Frequency Interference

A single-frequency interference usually appears on a television receiver as a discernible bar pattern that may be stationary or in motion. If the interference is an integral multiple of the nominal 60-Hz field frequency, it appears as a broad, stationary, horizontal pattern. If the interference differs slightly from a 60-Hz multiple, the bars travel up or down the picture. If the interference is weak, the impairment may more nearly resemble a flickering than a bar pattern, an impairment much more annoying than a stationary pattern. The effect depends on the flicker rate.

For frequencies at or near multiples of the line scanning frequency, the patterns are stationary or moving, vertical or diagonal bars. The bar structures become finer as the interfering frequency increases; the most critical frequencies are in the range of 100 to 300 kHz.

Similar phenomena are produced by single frequencies near the color carrier frequency. The high- and low-frequency characteristics must be determined as high or low frequencies relative to (i.e., displaced from) the color carrier frequency of 3.579545 MHz.

While there is a wide variation of subjective reaction to single-frequency interferences according to their frequency, stability, multiplicity, etc., the objective is usually stated as two simple numbers. First, the objective for a single interferer is taken as a signal-to-noise ratio of 69 dB where the signal amplitude is expressed in peak-to-peak volts (including the synchronizing pulse) and the interference is expressed as an rms voltage. The second expression for the interference is that the total weighted interference (including random noise) is to be 53 dB below the signal, the same value as that given previously for weighted random noise.

Echo

Echo refers to a signal produced by reflection at one or more points in a transmission path or generated by transmission irregularities and having sufficient magnitude and time difference to be perceived as

distinct from the signal received over the primary transmission path. Echoes may lead or lag the main signal and have characteristics that are described by four different picture impairments.

Types of Picture Impairments. A number of different picture impairments may occur as a result of reflections at points of discontinuity in the transmission path or as a result of transmission irregularities. All such picture impairments are subject (at least in theory) to control and reduction by some form of transmission equalization. These impairments are discussed in Chapter 18 but are mentioned again here to stress the facts that all are due to transmission discontinuities or departures from ideal transmission characteristics and may be dealt with in terms of echoes.

Streaking and Smearing. These are often considered separately but, for convenience, are considered here as one type of impairment. Both are described as unwanted lines or areas of brightness, usually observed to the right of a sharp brightness change in a picture, extending toward the right edge of the picture. Streaking extends undiminished to the right-hand edge; smearing diminishes substantially toward the edge of the picture. Both result from transmission irregularities at frequencies in the region of the field repetition rate (60 Hz), frequencies in the region of the line scanning frequency (15.75 kHz), and the first 10 to 15 harmonics of each.

Ringing. An oscillatory transient, called ringing, may occur in a signal at the output of a system as a result of a sudden amplitude change of the input signal. This results in closely spaced multiple repetitions of some picture elements whose reproduction requires frequency components approximating either the cutoff frequency of the system or the frequency of a sharp discontinuity within the passband. The ringing occurs at approximately the frequency of the discontinuity or of the band edge and is often accentuated by a rising gain characteristic preceding the discontinuity or band edge. Performance can be improved by extending delay equalization through the cutoff region.

Overshoot. This impairment is due to an excessive response to a sudden change in signal amplitude. It appears as a black outline to the right of white objects and as a white outline to the right of black objects. A sharp overshoot may be referred to as a spike; it is caused by excessive gain at high frequencies.

Flat and Differentiated Echoes. Echoes are complex phenomena whose interfering effects depend on echo amplitude, time separation from the main signal, the nature of the original signal, and the frequency characteristic of the echo source. If the echo essentially covers the entire transmitted band, it is referred to as a flat echo. If it has a sharp frequency characteristic, usually with stronger reflections at high frequencies, it is known as a differentiated echo. Differentiated echoes are generally less interfering than flat echoes. If the echo path accentuates the high frequency echo components at a rate of 6 dB per octave, the echo is less interfering than flat echo by about 15 dB.

Echo Objective. The echo objective for video transmission is a 40 dB signal-to-echo ratio. It is expressed in terms of a single, well-defined, long delayed (10μs or more) echo. In practice, many echoes are usually present, and each component echo must be weighted in accordance with a weighting function that represents the change in subjective effect with the time displacement of the echo. The weighted components are then combined on a power basis for comparison with the objective. A typical time-weighting function is shown in Figure 26-7. Recent analysis of subjective test data has shown that the function also varies according to picture content and the polarity of the echo [16].

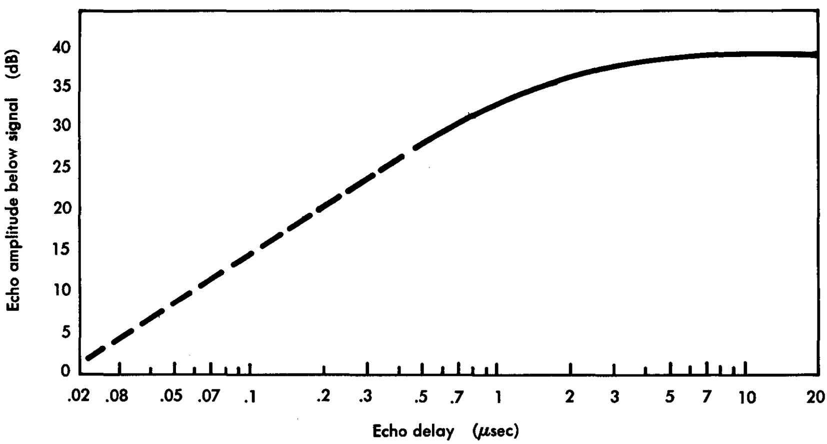

Figure 26-7. Single flat echo objectives (echo time weighting curve).

Any departure from flat amplitude response or linear phase response of a transmission channel can be expressed in terms of the Fourier components of the response functions. These components are expressed as cosinusoidal functions of the amplitude response and as sinusoidal functions of the phase response. The Fourier components can then be regarded as generating echoes which may be summed by power after the weighting function has been applied.

Crosstalk

Video crosstalk occurs when an undesired signal interferes with a desired signal. The objectives for crosstalk are expressed in terms of dB of loss in the coupling path between the two signals at 4.2 MHz at equal transmission level points. When the coupling path is flat with frequency, the crosstalk is called flat crosstalk. When the crosstalk path loss decreases with frequency at a specified rate in dB per octave, the coupling is called x dB differentiated crosstalk where x is the rate of loss decrease.

Where crosstalk can be seen, the interference appears as an image of the unwanted picture moving erratically across the wanted picture. The motion occurs because of the lack of synchronization between independent signals. As the crosstalk image moves across the picture, it appears to be framed. The apparent framing is formed by the synchronizing pulses of the interfering signal. The framing tends to be more noticeable than any feature in the image. The side frames, which extend from the top to the bottom of the wanted picture, interfere with the total wanted picture. The effect is similar to a windshield wiper moving across the picture; the term "windshield wiper effect" is sometimes applied.

If the crosstalk is weak (high coupling loss), neither the frame nor the image is discernible. At such a near-threshold point, only a slight flicker can be seen as the frame moves across certain portions of the desired picture. The subjective effect is more dependent on flicker rate than on crosstalk magnitude.

If the coupling loss varies with frequency, resulting in differentiated crosstalk, the interfering image may appear to be in bas-relief. However, the synchronizing pulses are still the most prominent feature in the crosstalk image since they have the largest rate of change.

The overall objective for crosstalk coupling loss between equal level points is dependent on the nature of the coupling path. Some typical path characteristics that may be encountered in practice are illustrated in Figure 26-8. The applicable objectives, expressed in dB of loss at 4.2 MHz, are as follows:

CROSSTALK PATH	OBJECTIVE, dB
Flat crosstalk	58
6 dB/octave	37
12 dB/octave	21
24 dB/octave	17.5

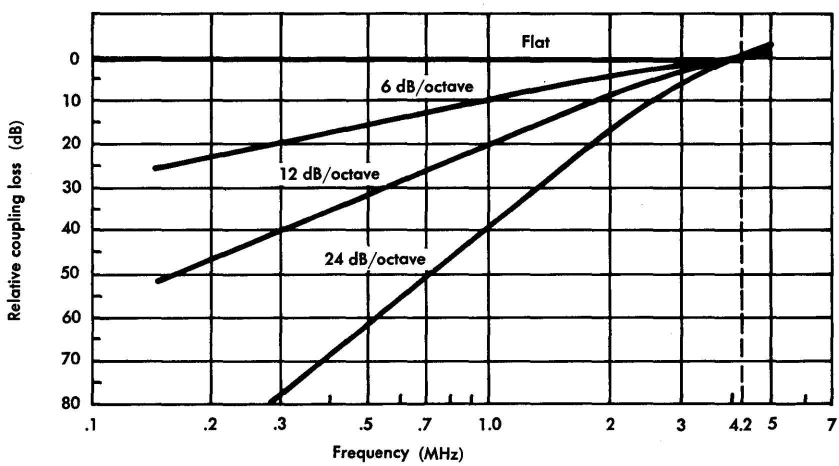

Figure 26-8. Coupling path loss characteristics.

Differential Gain and Phase

These impairments, which have serious effects on color television signal transmission, are described in Chapters 18 and 21, respectively. The objective for differential gain, which may produce undesired changes in color saturation, is 1.4 dB. The objective for differential phase, which produces changes in color hue, is 5°.

Audio/Video Delay

It is customary in the Bell System to transmit video and associated sound signals over separate transmission paths. If the difference in

absolute delay between the two paths is excessive, an impairment results because the picture and sound are out of synchronism; the sound is heard before or after the producing action in the picture. The objective is that the delays in the two transmission paths differ by no more than 55 milliseconds.

Luminance/Chrominance Delay

While the luminance and chrominance information in a video signal is transmitted over the same channel, the dominant components of one part of the signal are so far removed in frequency (over 3 MHz) from the other part that there can be a significant delay difference between the two. When this delay difference is excessive, the color portions of the signal are shifted relative to the luminance portions; i.e., there is a misregistration of color. Such an effect is most noticeable at sharp vertical edges of highly saturated color areas that are bounded by low-saturated color areas relatively free of detail [17].

The objective for the delay difference is 50 nanoseconds. It is expressed as the difference in delay between 3.6 MHz and frequencies below 200 kHz. Since the delay below 200 kHz tends to be constant, measurements are usually made at 200 kHz and 3.6 MHz to evaluate performance relative to the 50 ns objective.

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Chapter 27

Economic Factors

The quality of service provided by a telecommunications network must be based on an appropriate balance between customer satisfaction and the cost of service. To make service objectives meet the criterion of reasonable cost, compromises must often be made among the objectives themselves or between objectives and system development or application parameters.

A number of compromises may be used to illustrate the process of adjusting designs, applications, and objectives for economic reasons. There are, of course, no unchanging and absolute relationships among these factors. Guidelines tend to change with time because new systems, new services, and changing customer opinions bring about changes in the objectives. Furthermore, economic relationships are significantly affected by local and national economic factors such as inflation.

27-1 OBJECTIVES

The derivation and application of transmission objectives often involve judgment as to what can be accomplished within reasonable cost constraints, the compromises that result from such judgments, the reconciliation of one set of objectives with another, and the existing economic, environmental, and human resources factors. Consider first the determination of transmission objectives and the economic factors involved.

Determination of Objectives

The determination of telephone transmission objectives requires the use of subjective testing to establish the relationship between an impairment and observer opinions of its effect. The test results are then related to measured or derived performance parameters to obtain values for the grade of service that can be expected for

the combination of parameters involved. It is often possible at this point to determine the cost of achieving this grade of service and the effects of changing the objectives or the performance parameters. These changes can then be evaluated economically by comparing the results with the initial cost.

Qualitatively, the results are usually predictable. In nearly all cases, costs increase when objectives are made more stringent or when performance is improved. The characteristics of a cost/grade-of-service curve are obviously important, and the judgment that must be exercised in establishing the objectives is influenced by the nature of this curve.

In Figure 27-1, curve A shows a gradual increase in cost with improving grade of service and demonstrates many situations in which the simple prediction of increasing cost with improving grade of service is verified. Since the simple prediction does little to support engineering judgment, the establishment of the objective must be based on other criteria. On the other hand, curves B-B′ and B-B″ represent very different sets of circumstances.

Curve B-B′ shows that a relatively small increase in cost yields a substantial improvement in grade of service up to a good-or-better rating of 97 percent and that, regardless of cost, the grade of service cannot be increased beyond 98 percent. Thus, from the point of view

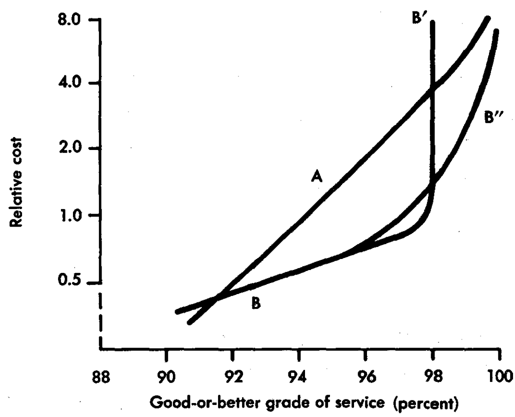

Figure 27-1. Typical cost curves.

of economic effects, any attempt to achieve higher than a 97 percent good-or-better grade of service would be wasteful.

Curve B-B″ shows another type of relationship in which costs increase somewhat faster above 95 percent good-or-better grade of service than below. The change is not nearly as abrupt as for Curve B-B′, and the achievement of a 96 or 97 percent grade of service (considered satisfactory) would be justified. The important point to note is that the derivation of cost curves such as those illustrated often provides strong support for determining objectives, either in terms of grade of service or more directly in terms of transmission objectives. Such curves may also be used to judge the cost of making desired improvements in performance.

Allocation of Objectives

As described in Chapter 25, objectives may be allocated to different sources of an impairment, the total objective for one type of impairment may be allocated to different parts of the plant (e.g., local or toll), or the total objective may be allocated to various parts of a transmission system. Each method of allocation is either directly dependent on or indirectly tempered by economic factors.

An illustration of how economic factors can affect the allocation of an objective to different sources of the impairment is seen in the design of analog submarine cable transmission systems. In most analog cable systems for land application, signal amplitudes are adjusted to produce optimum signal-to-noise performance. In submarine cable system design, the cost of cable repairs enters into the problem of noise allocation to various sources. If cable laying, aging, or other phenomena cause unanticipated misalignment of signal amplitudes in the positive (overload) direction, the increase in intermodulation noise might necessitate installation of additional equalizers in the cable, a costly operation. To guard against this possibility, submarine systems are usually operated at low signal amplitudes. The results are high margin against overload and the allocation of most of the message circuit noise objective to thermal noise. Intermodulation is seldom a controlling source of message circuit noise in submarine cable systems.

An illustration was given in Chapter 25 of how economic factors influence allocation of the objective for one type of impairment to various parts of the plant. It was pointed out that the 20 dBrnc maximum noise allocated to loops is such that no amount of expenditure in the loop plant could possibly improve the noise grade of service unless both loop and trunk objectives are made more stringent. At present, the noise resulting from trunks (carried predominantly on carrier systems in the intertoll portion of the network) controls the grade of service.

Finally, economic factors may affect the allocation of an impairment to different parts of a system. For example, in long analog cable transmission systems, the design objective for message circuit noise for a 4000-mile system is 40 dBrnc0. A possible allocation of this objective might be 37 dBrnc0 to the line repeaters and 37 dBrnc0 to terminal multiplex equipment. However, the difficulty and cost of achieving high quality performance in line repeaters (used in large numbers compared to the number of terminals) is recognized by a higher allocation to the line equipment. In most systems, the line repeaters are allocated 39.4 dBrnc0 and the terminal equipment 31.2 dBrnc0. This allocation, when further translated to individual units (repeaters or terminal equipment), still results in a per-unit allocation that is more stringent for a repeater than for the terminal equipment. However, the economic balance is such that a further allocation of the objective to the repeater (which already has been allocated about 87 percent of the total) would not result in significantly lower overall costs.

Economic Objectives

At certain times and under certain circumstances economic objectives may supersede all others. In times of economic stress, the desirability of improving performance or increasing route capacity may have to be subordinated to the necessity of reducing capital and operating expenditures. Such circumstances, undesirable as they may seem, must be recognized and improvements or expansion must be deferred.

In addition to the effects of economic stress, other less dramatic effects must be considered. Among the most significant of these is the availability of capital funds versus anticipated revenue. Sometimes it is necessary to keep outmoded equipment in service by paying for its maintenance from operating funds even though the results

of engineering economy studies have demonstrated the desirability of replacing the old equipment with new. When capital funds are in short supply, it is impossible to update equipment in the desired manner. This type of situation may be disclosed by engineering economy studies which compare initial capital outlays and estimated operating costs to available capital funds and anticipated revenue.

27-2 DESIGN COMPROMISES

Most of the compromises that must be made between objectives and cost are made during the development and design of new systems and new equipment. These compromises are made at every stage of development and design; the type of system to be developed, the features to be provided, the choice of circuits and physical designs, and the selection of components all relate to the balance between objectives (grade of service) and cost.

Circuit Devices

Devices used in electronic circuits include such elements as resistors, capacitors, inductors, transformers, transistors, and diodes. Each device selected for the circuit under design must obviously meet the requirements imposed by its function in the circuit. It must be of the correct value, capable of dissipating a certain amount of power, characterized by input/output relationships that are adequately linear, sufficiently reliable, etc. Even with these constraints, there is often a wide choice within which circuit needs can be met. Making that choice with good judgment involves consideration of costs and their relationship to the circuit requirements. Two significant factors are the manufacturing costs of the devices used and the ingenuity of the designer in utilizing a device to serve more than one function.

The benefits of mass production are evident in the reduced cost of devices. Also, economic benefits are usually effected when a device can be made to serve multiple functions, as do many of the devices in telephone station sets. The quantity of sets manufactured annually is so high that even a fraction of a cent saved in one device yields a significant manufacturing cost saving. As a result, a great deal of effort is devoted to design and redesign of the station sets and of each device used. In such applied cost reduction studies, careful attention must always be given to every aspect of the design, including the environmental conditions that are found in the operating

plant (heat, humidity, voltage, handling, etc.) as well as the circuit requirements.

Circuits

As discussed here, circuits are packaged entities of interconnected electronic devices that provide some specific function such as modulation, multiplexing, or amplification. A circuit may include electronic networks, filters, and equalizers, often referred to as *apparatus.*

The design of circuits has progressed rapidly in recent years from point-to-point connection of devices through printed wiring techniques to a gamut of thin film, thick film, and integrated circuit arrangements that have evolved with the development of solid state technology. With the wide choice of circuit arrangements available, careful attention must again be paid to economic factors. If large numbers of identical circuits are to be built and close control of circuit performance is required, integrated circuits are likely to be a good first choice. Sometimes, the added expense of integrated circuits in small quantities is justified because the reproducibility of integrated circuit performance is high.

An interesting illustration of circuit selection based on economic factors hinges on the selection of devices involved in the design of narrowband elimination or bandpass filters. In cases where the total available band for achieving prescribed characteristics is wide, the design may employ electronic devices, but if the efficiency of bandwidth utilization must be high and the available bandwidths are small, piezoelectric crystals may be needed to achieve the desired characteristics. The cost of the resistors, capacitors, and inductors used in an electrical filter design is, in most cases, much lower than the cost of crystals and the necessary additional devices. The choice depends on available bandwidth and the stringency of the requirements.

Physical Design

The physical design of equipment and facilities is greatly influenced by the costs of maintenance and operation as well as by the costs of manufacture and installation. Recent trends in physical design have been influenced by the decision to adopt new standards in building design and by the recognition that both transmission and operation

could be improved by integrated designs of equipment bays [1, 2]. These integrated designs, sometimes called unitized bays, include many more combinations of transmission, signalling, and switching system interface equipment than were formerly provided in a single bay. Some of these combinations have been made possible by the development of miniature devices and some by improved techniques of bay wiring and functional circuit interconnection. The new designs result in a significant reduction in office wiring, the elimination of a number of cross-connect frames, reduced congestion of cable racks and cross-connect frames, and a reduction in the number of jack fields.

The most significant feature of the new building design standards is the reduction of ceiling height and the concomitant standardization of 7-foot equipment bay heights. The packaging of electronic circuits must now be consistent with the 7-foot bay standard, but in order to serve existing buildings with reasonable efficiency, bays are also designed to old standards. The necessity for designing equipment for several bay heights has led to a number of design compromises that will eventually be unnecessary. As buildings of new design become predominant, bay designs for the older buildings will no longer be economically justifiable.

Unitized bay designs have led to a set of design compromises different from those relating to building design. Facility terminals, as the new designs are called, contain all voice-frequency terminal equipment needed for a specific facility. In general, transmission performance improves, but there may be some minor limitations on the features that can be provided and the flexibility of equipment use.

The advent of solid-state technology has also led to situations in which the solutions to design problems have resulted in various compromises. A transistor dissipates less power than an electron tube, but transistors are so much smaller that many more can be packaged into a given volume than electron tubes. The result is higher heat dissipation per unit of volume for transistor circuits, so temperature control has become a problem in packaging solid-state devices. Since the higher density of components has lead to higher weight per unit of volume in many designs, floor loading must be reconsidered. Thus, physical designs have interacted with circuit and system designs to bring about new adjustments in objectives and design features. The process of adjustment and compromise is continuous and parallels the development of all aspects of new technology.

Systems

The design of systems follows the same pattern of compromise as has been outlined for components, circuits, and physical designs. System features and design criteria must be considered in respect to feasibility and cost. Reliability, maintainability, restoration of service, automatic versus manual testing, remote control and telemetry, and many other operational features must all be weighed carefully in terms of service and cost.

The balance among system alternatives and cost factors plays an important role in determining whether to develop a new system. An example, illustrated by Figure 27-2, involves the cost of a carrier system relative to the cost of copper pairs for voice-frequency transmission. Costs for carrier and voice-frequency transmission are normalized to a value of unity at the point where the two costs are equal. As illustrated, the cost of carrier transmission has a base, A, representing the fixed cost of the terminal equipment. To this base cost is added the line cost (medium and electronics), which increases approximately linearly with distance. The cost of voice-frequency transmission increases linearly from a base of zero except for discontinuities, designated B, introduced by possible gauge changes and the periodic need for VF repeaters. The slope of the VF facility cost curve is directly affected by the total cable cost and the number of pairs per circuit.

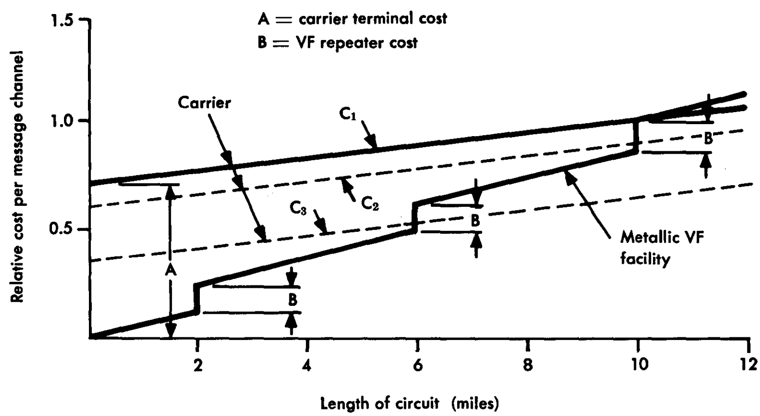

Figure 27-2. Comparison of costs for very short circuits.

It can be seen that the cost/distance curve for the carrier system is already less steep than for voice-frequency transmission. Further, it is evident that even if this slope is significantly reduced, the cost of a circuit is not materially affected because of terminal costs. The conclusion is that only a significant reduction of the terminal cost, A, can be expected to improve the position of carrier transmission relative to that of voice-frequency transmission. Curve C_2 shows the effect of a terminal cost reduction of about ten percent, a reduction that has no effect on the relative markets for the two transmission modes because the crossover point of the cost curve is still at ten miles. However, with a different set of curves and crossover points, a ten percent reduction might be very significant and lead to a different conclusion.

Curve C_3 shows the effect of a terminal cost reduction of about 50 percent. This may well provide encouragement for the development of new carrier terminals if the cost reduction appears to be possible, because the crossover point of the carrier and voice-frequency transmission cost curve is now at six miles. In addition, it would be necessary to show that there are large numbers of circuits in the range of six to ten miles and that there could be a high expectancy of achieving the 50 percent cost reduction by terminal redesign.

Many studies of the type described have been made to guide the development of T-type and N-type carrier systems. The curves of Figure 27-2 are representative but are not based on any specific study results. Many other details must be included in a transmission system development study, such as the gauge of wire and the loss to which the circuits are designed.

A second example of cost factors in transmission design is shown in Figure 27-3, which illustrates the effect of electronic equipment costs on the total line costs in long-haul analog cable transmission systems. The channel capacity or bandwidth of a number of systems is shown relative to an arbitrarily selected bandwidth taken as unity and to an arbitrarily selected unit of line cost. The line costs for a number of systems are then plotted in terms of electronic and nonelectronic components. Nonelectronic cost components include the cost of cable, installation, and right-of-way.

Examination of the curves of Figure 27-3 shows that as the normalized bandwidth increases beyond a value of 3, the cost of

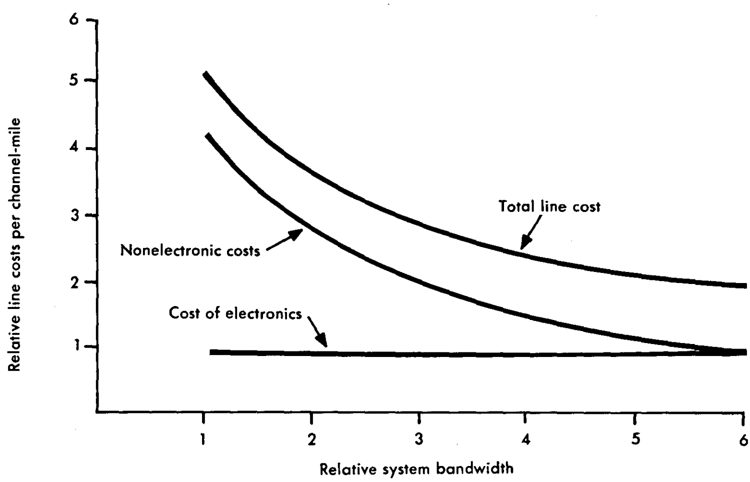

Figure 27-3. Electronic and nonelectronic line costs, analog cable systems.

electronic equipment increases gradually. More important, the cost of nonelectronic components and electronic components is about equal for a normalized bandwidth of 6. Thus, it may be expected that any additional increase in bandwidth would show that the total cost starts to increase, and the development of new systems would be financially questionable. Other means of transmission should probably be considered.

27-3 APPLICATION COMPROMISES

Economic factors influence transmission problems in the field much the same as in the laboratory environment. In the field, the questions that arise involve long-range and short-range planning activities; the optimum selection of equipment, transmission media, and systems; and the allocation of funds to satisfy necessary operating functions.

Components

In the field environment, the word components refers to units of equipment such as filters, equalizers, amplifiers, or balancing networks. In designing and laying out loops and trunks, the proper selection of such components plays a significant part in achieving performance consistent with established objectives and, at the same time, in satisfying economic constraints.

In addition to the decisions that must be made to satisfy technical objectives, the choice of equipment components must often include consideration of general trade equipment components that can be purchased outside the Bell System. Many suppliers have introduced equipment in the market that meets the needs of telephone operating companies. Thus, a knowledge of outside suppliers' equipment, its performance capabilities and cost is imperative.

Systems

In an operating company the planning function typically includes engineering studies that involve system choices in which economic factors are important. Many economic studies must be made since the choice of system depends heavily on cost relationships. Cost curves similar to Figure 27-2 provide a good basis for solving system applications problems as well as design and development problems. By combining cost curves and a projected distribution of circuit lengths, it is often a simple process to decide the most economical choice of facilities. However, where system capacities are large, analysis may be quite complicated.

In very heavily populated areas, where large circuit cross-sections are needed, there may be more than the usual choices of systems. In most cases, the choice is primarily made from several alternate plans for increasing the amount of paired copper cable, and the use of T- and N-type carrier systems. In larger metropolitan areas, the choices may be increased by the possibility of using microwave radio systems or digital coaxial cable systems. Several such systems are now available for metropolitan area applications.

Efficient use of maintenance personnel is another economic factor in choosing a system. A number of equipment types are now available to make measurements and surveillance tests automatically and even to control certain operational functions remotely. In any planned installation or expansion program, the cost of using such equipment must be compared with the more conventional manual and on-site maintenance methods.

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Chapter 28

International Telecommunications

The evolution of telegraph communications, the invention of the telephone, the development of radio communication, and the expansion of the total communication network have led to one of the world's most highly developed telecommunication systems on the North American continent. Whatever the principal reasons for this tremendous, but isolated growth in the United States and Canada (invention, corporate organization, common language, few and open international frontiers, etc.), little need was initially evident for coordination with other nations or for the establishment of international objectives or standards of performance. Thus, standards which in some cases, are quite similar to those now applied internationally, yet in other cases are quite different, have evolved independently in the United States and Canada.

When transatlantic telegraph and then radio-telephone communications were established, the need for some form of intercontinental coordination was recognized for the first time. The need for continuing and expanding coordination has been more evident as submarine cable and satellite communications have become realities. Today, the U. S. Government, a number of American common carriers, and American industrial and scientific organizations (including manufacturers) are members and active participants in international telecommunications organizations. The increasingly intense use of the radio spectrum, the enlarged international market and the increasing use of international direct distance dialing are bringing about increased standardization of international communications. This trend is supported, in part, by the proliferation of telecommunication equipment manufacturers, whose international marketing efforts are naturally enhanced when their equipment satisfies international recommendations and standards. International transmission planning permits the use of various internal trans-

mission plans nationally, but international standards are met at international switching offices and on international circuits.

28-1 THE INTERNATIONAL TELECOMMUNICATION UNION

While international coordination of telecommunications did not directly affect the development of the North American network, the need for coordination and cooperation among European nations was evident as long ago as 1865. At that time, the International Telegraph Union was formed by a convention in Paris attended by twenty delegations from different European countries. Today there are nearly 150 members of the International Telecommunication Union (ITU), the modern descendent of the International Telegraph Union. The ITU engages in worldwide activities and is one of the specialized agencies of the United Nations, which recognizes it as the sole specialized agency competent for telecommunications [1, 2, 3].

Three international technical advisory committees were formed to deal with various aspects of international telecommunications. These committees were an outgrowth of the International Committee for Long Distance Telephony*, commonly referred to as the CCI, inaurated in 1924. The three committees were called (1) the International Consultative Committee for Telegraph (CCIT), the International Telephone Consultative Committee (CCIF), and the International Radio Consultative Committee (CCIR). By 1939, when work was interrupted by World War II, these committees had succeeded in solving most of the traffic, operating, and radio coordination problems to the satisfaction of all Administrations [4]. The American Telephone and Telegraph Company participated in the activities of these early committees, first as an observer and then, after 1929, as a fully qualified member.

At present, the relationships between the ITU and the U. N. (and several other specialized agencies of the U. N.) provide for cross-representation between organizations, but the ITU has retained its independence. The ITU acts essentially as a technical advisory and

* The original name of this organization was the *Comité Consultatif International des Communications Téléphoniques à Grande Distance.*

administrative body. In 1956, two of its committees, the CCIF and the CCIT merged into the International Telegraph and Telephone Consultative Committee (CCITT).

The ITU and its principal organs maintain an active interest in all aspects of international telecommunications, including the studies of a wide variety of technical problems and the coordination of international traffic and operating procedures. In addition, a special working party of the CCITT and the CCIR (two of the principal organs of the ITU) have produced a handbook to assist the administrations and private operating agencies in an appreciation of the technical and economic problems involved in the planning of transmission systems [5]. Other special working parties have prepared handbooks on national automatic networks and on local networks. These handbooks contain information on current practices in countries that have highly developed telecommunication facilities and networks and are intended to help other countries fill their telecommunications needs.

International cooperation regarding satellite communications has been fostered by studies and recommendations of the CCIR. With the advent of launch vehicles capable of placing substantial radio communication equipment into earth orbit, the CCIR began studies of the commercial feasibility of international communication satellites which culminated in recommended criteria for this mode of communication. The radio frequencies required by early satellites were located in a frequency band bounded by excessive rain absorption above 10 GHz and high galactic noise below about 1.0 GHz. In order to share the available useful frequencies with existing microwave radio systems, equitable criteria had to be devised and international agreement obtained. In 1963, an Extraordinary Administrative Radio Conference (of the ITU), to which the CCIR is the consultative technical organization, adopted initial sharing criteria (e.g., signal powers, frequencies, and allowable interference) for satellites, earth stations, and the terrestrial systems affected. Their conclusions became part of the international radio regulations upon treaty ratification by the various countries involved, including the United States. The initial criteria prevailed until 1971 when a World Administrative Radio Conference adopted new criteria and allocated additional frequencies above the earlier 10 GHz maximum. This action was based on recommendations resulting from CCIR studies.

Organizational Structure of the ITU

The ITU consists of four permanent organs: (1) a General Secretariat directed by the Secretary-General and a Deputy Secretary-General, (2) the International Frequency Registration Board (IFRB), (3) the International Radio Consultative Committee, and (4) the International Telegraph and Telephone Consultative Committee. The General Secretariat provides liaison between Administrations and private operating agencies throughout the world and is entrusted with the administrative and financial services of the ITU; it also has a Technical Cooperation Department whose experts work in various countries to provide technical assistance where needed [3, 6].

International Frequency Registration Board. The IFRB acts as the recipient of information from the Administrations to record the frequency assignments of certain types of radio stations. It also acts, wherever possible, to predict potential interference and to adjudicate complaints of radio interference between Administrations by suggesting solutions to real or incipient problems.

International Radio Consultative Committee. This committee studies technical questions relating to radio transmission and operations and issues recommendations based on technical reports resulting from their studies. The committee is made up of representatives from all members of the ITU Administrations and recognized private operating agencies. When authorized, industrial and scientific organizations may participate on a consultative basis. The plenary assembly assigns work to various study groups and working parties whose reports are received at plenary assemblies held by the CCIR approximately every three years. The reports of the study results submitted and of the resulting actions taken by the plenary assemblies are published by the ITU.

International Telegraph and Telephone Consultative Committee. The CCITT, like the CCIR, is made up of representatives from all members of the ITU, some recognized private operating agencies, and industrial and scientific organizations. The CCITT studies technical, operating, and tariff questions connected with international telecommunications. The study groups and working parties present the results of their studies to plenary assemblies of the CCITT, held

about every three years. These reports, together with other actions of the plenary sessions of the CCITT, are published by the ITU in volumes whose colors are chosen to be distinctively related to a particular plenary session.*

Study Groups and Working Parties

Most of the technical work of the CCIR and the CCITT is carried out by study groups, special study groups, and joint working parties that are assigned responsibility for specific types of problems or fields of investigation. These groups meet as required in order to consider their assigned questions and problems. Figure 28-1 shows a number of study groups of the CCITT, some of which operate jointly with the CCIR. Regular study groups are designated by Roman numerals and, in respect to their responsibilities, they fall within a functional division of one field of study. Special study groups, designated by letter, are involved in more than one field of study. They may be formed of members from the CCIR, the CCITT, or both. In Figure 28-1, arrows are used to indicate interactions between special study groups (SP. A, SP. C, and SP. D) and the functional study groups. Interactions within a field of study are not shown. Working parties are formed within a study group to study a particular problem or field of investigation; they may be permanent or they may exist only for the time necessary to complete an assignment. Study groups have the responsibility of responding to specific questions assigned by a plenary assembly of the CCIR or CCITT; these questions and subsequent recommendations are included in the official publications of the CCIR or CCITT. The study groups also prepare a list of questions and study programs for the following plenary period (the period between plenary assemblies). The questions are proposed by the members of the CCIR or CCITT. Formal approval by the plenary assembly is required for recommendations and questions to become official.

* Examples are the Red Books, which cover the meetings of 1958 at Geneva and 1960 at New Delhi (Ist and IInd Plenary Assemblies); the Blue Books, which cover the meeting of 1964 at Geneva (IIIrd Plenary Assembly); the White Books, which cover the meeting of 1969 at Mar Del Plata (IVth Plenary Assembly); and the Green Books, which cover the meeting of 1972 at Geneva (Vth Plenary Assembly).

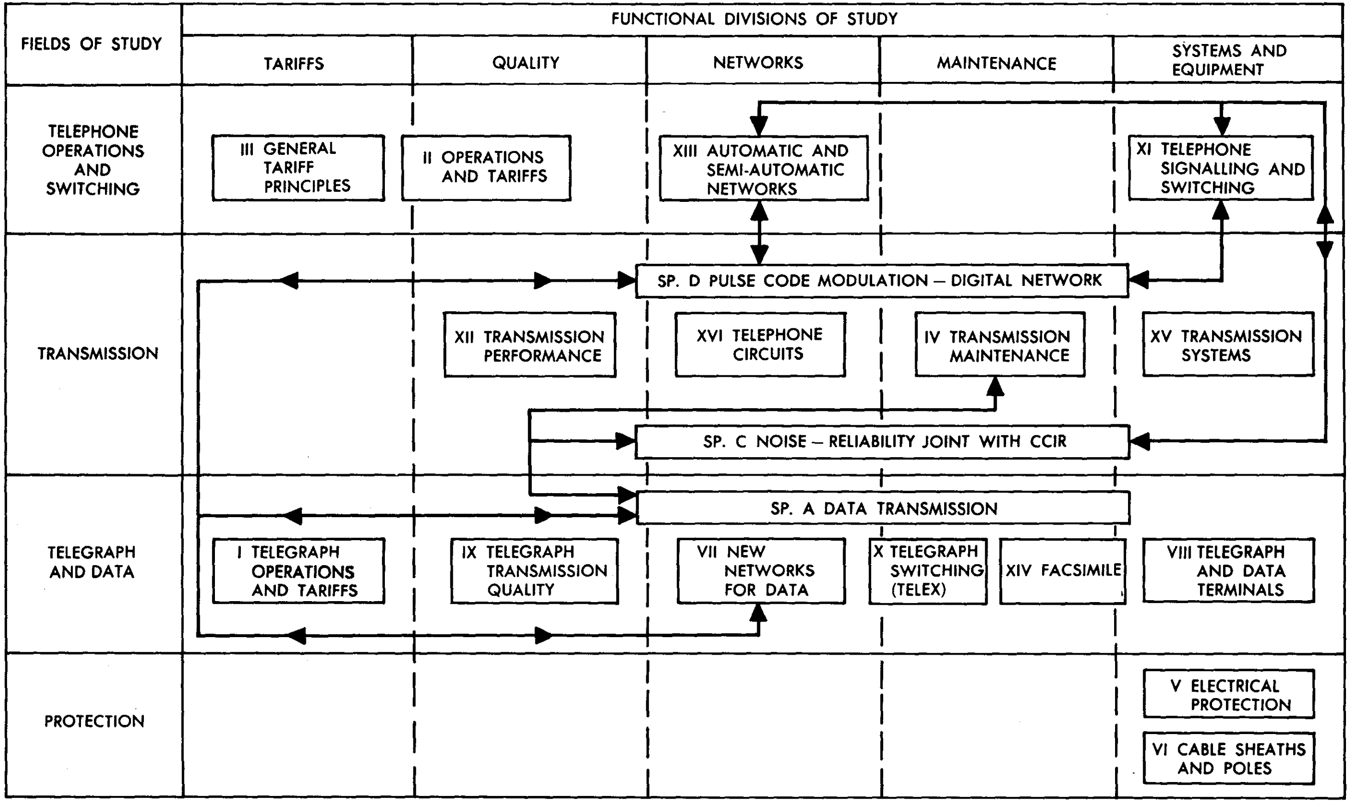

Figure 28-1. CCITT study groups.

Characteristics of International Operations

The major differences between national and international operations of telecommunication networks involve geography, language, law, and politics. The ITU has performed admirably in solving the related problems by patient negotiation and by the dedicated services of the many persons representing its membership. The ITU operates on the basis of voluntary membership with the assumption that it is in the members' best interests to observe the conventions, regulations, and recommendations of the Union [7].

28-2 THE EVOLVING INTERNATIONAL NETWORK

The members of the ITU, through recommendations of the CCITT, have agreed on the goal of providing customer dialing of international calls on a worldwide basis. A general plan for achieving this goal has been agreed upon and is being implemented on a step-by-step basis. Operator and customer dialing of international calls is already a reality in many countries. The capability for operator and customer dialing requires all-number calling, already in effect or planned for most countries.

World Numbering Plan

Worldwide operator and customer dialing requires a worldwide numbering plan. An appropriate plan, worked out by the CCITT, divides the world into eight zones, as shown in Figure 28-2. Each country is given a 1-, 2-, or 3-digit country code number, the first digit of which identifies the world numbering zone. In the multinational North American zone 1, which is already organized into a single integrated numbering plan, the single digit 1 is used as the country code of all the countries in zone 1. Another interesting detail is that the European zone has so many countries warranting two-digit codes that it has been assigned the initial digits 3 and 4.

For worldwide dialing, a customer or operator must first dial an international prefix. Ambiguity between national and international numbers employing the same initial digits is overcome by first dialing the international prefix. In the North American network, the prefixes for international dialing are 01 for calls requiring operator assistance and 011 for other calls. After the international prefix, the country code and the national number of the called station are dialed. The international numbering plan places the restriction that, after the

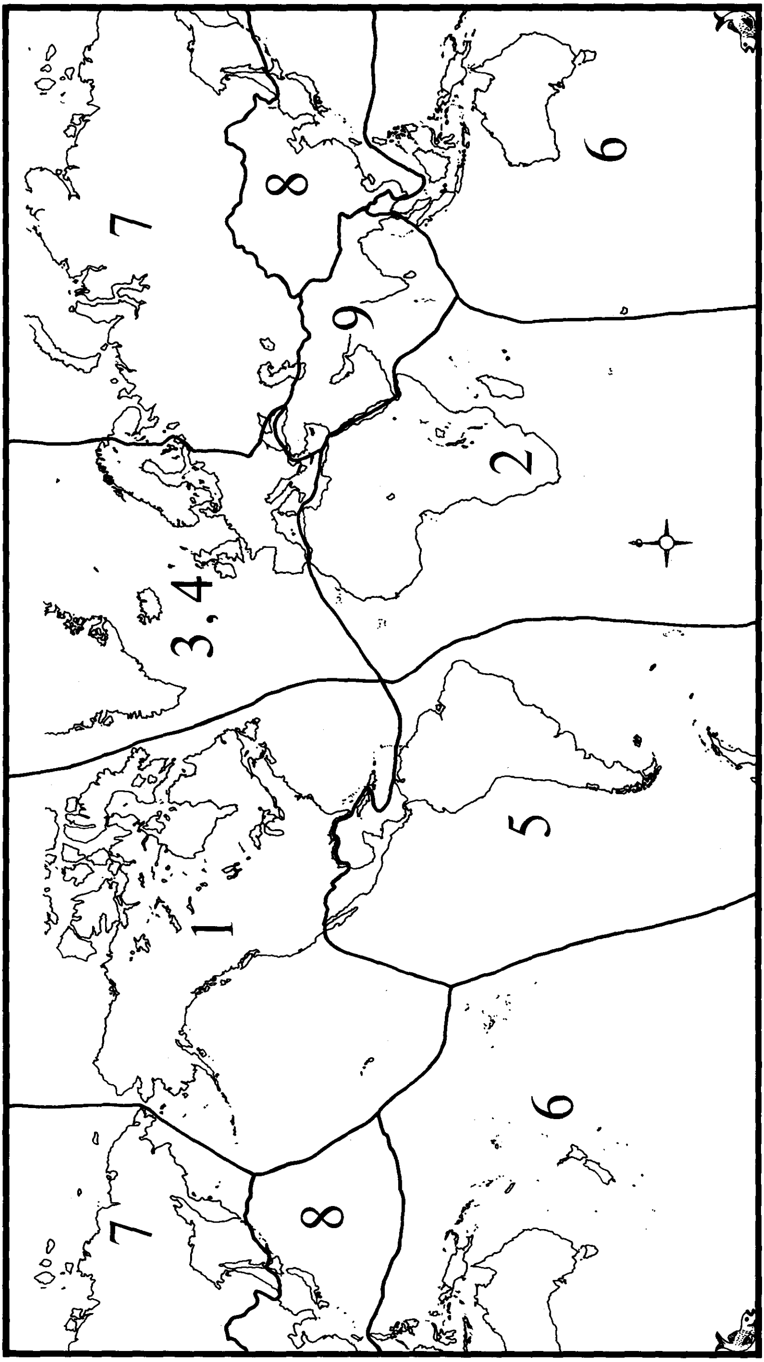

Figure 28-2. World numbering zones.

international prefix, there may be a maximum of twelve digits in the international telephone number.

Some of the capabilities implied by the numbering plan just described are yet to be implemented. In some cases, the digit capacity of registers in local and toll offices must be expanded. Call routing from an originating office to the appropriate international switching center must be provided.

Signalling

When serious consideration was first given to direct dialing of transatlantic calls, it was immediately noted that the European and North American signalling systems were incompatible. Furthermore, none of the existing systems were compatible with the needs of the TASI system designed for use with the early submarine cable systems.

Early submarine cable operation was carried out by manual ringdown signalling. In 1960, agreement was reached by the British, French, and German Administrations with the Bell System on a specification for an intercontinental signalling system. The system, sometimes called the Atlantic system, was compatible with TASI, provided for two-way operation of circuits, and provided practical interfaces with the European and North American signalling systems. It used a modified version of the North American multifrequency pulsing for the transmission of address information and a new 2-frequency system for supervisory signals. In 1960, both of the latter frequencies were in standard use in Bell System signalling systems.

The CCITT was requested to study the Atlantic system for standardization as a recommended intercontinental signalling system. The system was accepted by the CCITT with some minor changes and was designated the CCITT Signalling System #5. Subsequently, the CCITT standardized a common channel signalling system (CCITT #6), designed to operate with stored program switching systems and capable of providing features not available in System #5.

Traffic and Operating

While most international calls were formerly person-to-person, station-to-station calling is commonly used between many countries

and is increasingly available for both incoming and outgoing U. S. international calls. Credit card and collect calls are also accepted for calls between many countries and are also more widely used in international telephony.

An international operator may sometimes have language difficulties or be unable to interpret a tone. To alleviate these problems, calling operators are able to ring forward and bring in an assistance operator in the terminating country. A language digit is prefixed to the called number by the switching machine and pulsed forward to prepare the distant equipment for receipt of a subsequent language-assistance signal.

Routing Plan

A routing plan that is similar in many ways to the routing plan used in the North American network has been recommended by the CCITT. The hierarchical arrangement of the worldwide plan utilizes three levels of international switching centers (transit centers), designated CT1, CT2, and CT3; CT1 represents the highest rank in the hierarchy. The plan is shown in Figure 28-3.

High usage trunk groups between any pair of CT offices are established wherever they can be economically justified. Provisions are made for alternate routing of overflow traffic from high usage groups to alternate transversal trunk groups and then to the final group. An example is given in Figure 28-3. For a call from CT3 on the left to CT3 on the right, attempts would be made first to use the direct group between these offices. As implied by the arrows, attempts would be made to route the call to CT2 and then to CT1 on the right. Finally, the call would be offered to the final route.

According to the routing plan, CT1 offices are to be interconnected in pairs by circuit groups having low probability of blocking. In exceptional cases, two CT1 offices may be interconnected through an intermediate transit center of unspecified rank (CTx). This is done only where significant economies may be realized and only if transmission and other standards of service quality are met.

The CT1 offices are important in the world routing plan. Locations are chosen to satisfy national and international economic considerations as well as technical requirements for switching and trans-

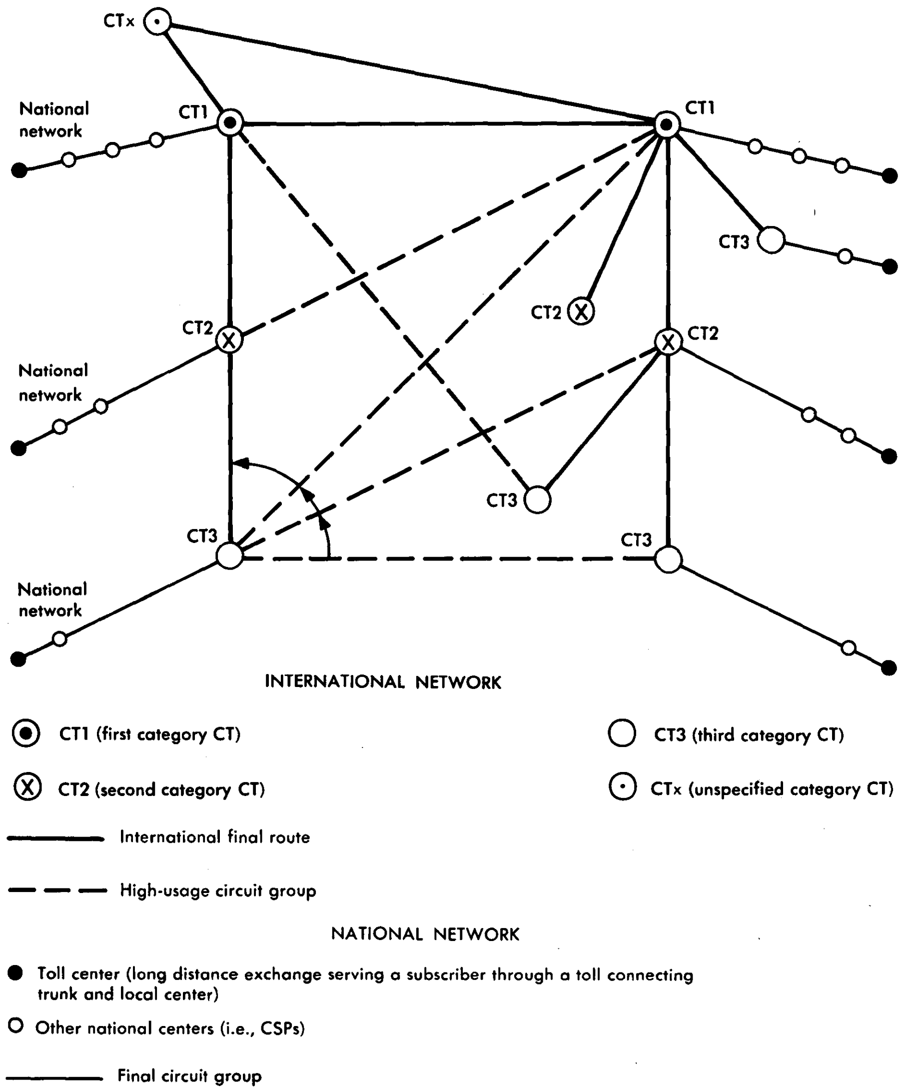

Figure 28-3. International routing plan.

mission. Each country in which a CT1 is located must be concerned with the costs of interconnecting that CT1 with all others by direct circuit groups. The CT1 offices are few in number and their recommended locations are strategically chosen on the basis of the in-

transit flow of international transit traffic. These offices are concentration points for the traffic from a very large area. A number of CT1 offices have been designated or proposed by ITU members to implement the world routing plan.

The maximum recommended number of tandem-connected trunks that may be used for an international call is fixed by the CCITT at 12, with a maximum of six international circuits. In some cases and for only a small percentage of calls, the total number of tandem circuits may be as high as 14; even in these cases, the maximum number of international circuits is limited to six. An international call involving six international circuits would be one routed through transit centers in the following manner: CT3, CT2, CT1, CTx, CT1, CT2, CT3.

Final route engineering of a worldwide network for efficient handling of busy-hour traffic poses interesting problems caused by the concentration of traffic during a few hours of the day due to time zone differences. The CCITT has initiated a study of solutions to these problems by flexible routing and some form of network management.

Transmission and Maintenance

The possibility of 12 or even 14 tandem-connected circuits increases the likelihood that international connections may be impaired more than domestic connections. In addition to the greater lengths and increased number of circuits involved, the variation in types of facilities also increases. These factors increase the probability of increased loss, loss variation, noise, distortion, and propagation delays. Unless very stringent controls are imposed, there is an increased likelihood of encountering multiple echo suppressors on an international connection. All of these factors make necessary a high degree of control over transmission design and maintenance.

The procedures involved in establishing and maintaining international circuits have been and continue to be the subjects of study by members of the CCITT. The resulting recommendations cover such aspects of international circuits as the types of facilities, switching systems, and signalling arrangements; detailed responsibilities for control, trouble locating, testing, and maintenance; and procedures for operating the international network. At the time international

circuits are established between two countries, detailed agreements (largely based on current recommendations of the CCITT) are reached on all of the specific items involved in maintenance.

28-3 TRANSMISSION PARAMETERS AND OBJECTIVES

The CCIR and CCITT have defined a large number of transmission parameters and have established or recommended many transmission objectives for the international telecommunication network. These are thoroughly covered in documents published by the ITU [8, 9]. Space does not permit a comprehensive discussion here, but transmission level points, noise, and channel loading serve to illustrate the manner in which transmission problems are treated internationally.

Currently, in the reports published by ITU, transmission parameters are expressed in decibels. Some parameters are also expressed in decimal units of the international system of units. For example, noise and noise objectives are expressed in picowatts and picowatts per kilometer.

International practices and recommendations include the use of a *reference level,* a term that is analogous to the 0 TLP used in the Bell System. The reference level point is sometimes referred to as 0 dBr (dB relative level). For four-wire operation, the transmitting end of the circuit is defined as a —3.5 dBr point at the "virtual" switching point, a theoretical point whose exact location depends on national practice.

Noise

The basic unit of noise measurement used in international practice is the picowatt (pW), i.e., 10^{-12} watt. It should be noted that for a 1000-Hz signal, this is the same reference as that used in the Bell System. In international maintenance practice, the standard test signal may be 800 or 1000 Hz. The picowatt may be expressed in decimal or logarithmic terms; the equivalent values are $1\ \text{pW} = 10^{-12}\ \text{W} = 10^{-9}\text{mW} = -90\ \text{dBm}$.

Message circuit noise is measured, according to CCITT recommendations, by a noise measuring set called a *psophometer.* The set is equipped with a weighting network that has a characteristic

somewhat similar to the C-weighting characteristic used in the Bell System. The two characteristics are shown for comparison in Figure 28-4. For general conversion purposes, it is usually sufficient to assume that the psophometric weighting of 3-kHz white noise decreases the average power by about 2.5 dB (compared with the 2.0-dB factor for C-message weighting). The term *psophometric voltage* refers to the rms weighted noise voltage and is usually expressed in millivolts.

The (rounded) conversion factor recommended by the CCITT for practical comparison purposes is that 0 dBm of white noise measured by a psophometer (1951 weighting) is equivalent to 90 dBrn measured on a 3A-type noise meter with C-message weighting. This conversion, which applies to white noise in the 300 to 3400 Hz band, is not valid for other noise shapes because of the differences between psophometric and C-message weighting [10].

The relationships between various CCITT and Bell System noise units are summarized in Figure 28-5. The data are particularly useful for conversion from one noise unit to another since an estimate of the frequency spectrum effects can be obtained by comparing the three conditions tabulated. The 1-kHz values are given for comparison of the various conditions used. The 1-kHz psophometric reading appears 1 dB high because the psophometric reference is 1 pW at 800 Hz. The 0- to 3-kHz band of white noise approximates the noise obtained from a message channel. The broadband white noise readings are proportional to the total area under the weighting curve and

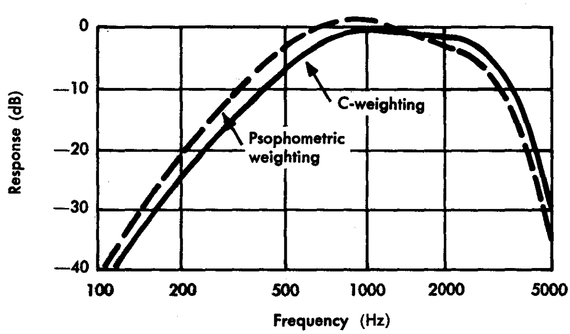

Figure 28-4. Comparison of noise weighting characteristics.

NOISE UNIT	TOTAL POWER OF 0 dBm		WHITE NOISE OF —4.8 dBm/kHz NOT BAND-LIMITED
	1 kHz	0 TO 3 kHz WHITE NOISE	
dBrnc		88.0 dBrnc	88.4 dBrnc
dBrn 3 KHz FLAT	90.0 dBrn	88.8 dBrn	90.3 dBrn
dBrn 15 KHZ FLAT	90.0 dBrn	90.0 dBrn	97.3 dBrn
Psophometric voltage (600 ohms)	870 mV	582 mV	604 mV
Psophometric emf	1740 mV	1164 mV	1208 mV
pWp	1.26×10^9 pWp	5.62×10^8 pWp	6.03×10^8 pWp
dBp	91.0 dBp	87.5 dBp	87.8 dBp

Figure 28-5. Comparison of noise measurements.

thus give significant information concerning the weighting function above 3 kHz. Similar data for other conditions or weightings can be obtained by integrating the appropriate weighting characteristic over the required frequency band.

Channel Loading

To simplify calculations in carrier system design, the CCITT has adopted (Recommendation G.223) a conventional value, —15 dBm0, to represent the mean absolute power of speech and signalling currents [8]. When the —15 dBm0 value was established, it was based on a determination of expected channel signal loads. Analog system overload is discussed in Chapter 7 where *Definition 2* is the CCITT-recommended definition of overload.

The problem of loading has been under further study in recent years to determine whether the adopted value should be changed to reflect the transmission of new signal types. The approach that now appears most promising is that the amplitudes of data and other types of signals will be made compatible with —15 dBm0. One step has been to recommend a maximum sending reference equivalent (minimum loss) from the subscriber to the first international circuit. Also, several study groups have agreed that data and voice-frequency telegraph signals are to be reduced to —13 dBm0.

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